AD-A272 281

FEAP-TR-FE-93/15
July 1993

FACILITIES ENGINEERING
APPLICATIONS PROGRAM

TECHNICAL
REPORT

# Steam Dispatching Control System Demonstration at Fort Benjamin Harrison



by
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# REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188



1. AGENCY USE ONLY (Leave Blank)

2. REPORT DATE
July 1993

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
Steam Dispatching Control System Demonstration at Fort Benjamin Harrison

5. FUNDING NUMBERS
FEAP-EB-FJ1

6. AUTHOR(S)
Christopher L. Dilks, Ralph E. Moshage, and Mike C.J. Lin

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Construction Engineering Research Laboratories (USACERL)
PO Box 9005
Champaign, IL 61826-9005

8. PERFORMING ORGANIZATION REPORT NUMBER
FEAP TR-FE-93/15

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Engineering and Housing Support
ATTN: CEHSC-FU-M
Bldg 358
Fort Belvoir, VA 22060-5516

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
Currently most Army Central steam heating systems operate by maintaining a constant steam pressure regardless of actual steam demand. This method offers some operational convenience, but is often the cause of significant energy losses. Researchers at the U.S. Army Construction Engineering Research Laboratories (USACERL) have investigated the Steam Dispatching Control System (SDCS), a control system that lowers supply steam pressure—and therefore steam temperature—to slightly above the amount needed to meet the steam demand. The lower steam temperature and reduction in steam loss (from leaks and faulty traps) result in lower heat losses and higher energy savings. Limiting steam pressure can diminish the amount of excess heat loss in the distribution system while still meeting the demand.

The Army's Facilities Engineering Applications Program (FEAP) chose Fort Benjamin Harrison, IN, as the Army demonstration site for SDCS.

Researchers found that use of SDCS is technically and economically viable improvement over current operating procedures. Analysis based on demonstration results show that the simple payback for SDCS is less than 1 year. The results of this demonstration are generally applicable to installations with a large central heating plant and a substantial steam distribution system. Findings, indicate that energy savings form SDCS are significant regardless of what type of fuel powers the boiler. The authors note that, during the initial evaluation of a potential SDCS application, attention must be paid to the condensate return to ensure that it will operate properly.

14. SUBJECT TERMS
Fort Benjamin Harrison, IN
Central heating plants
steam dispatching control system (SDCS)
energy conservation

15. NUMBER OF PAGES
96

16. PRICE CODE

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFICATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | SAR |

# FOREWORD

This research was performed for the U.S. Army Engineering and Housing Support Center (USAEHSC) under the Facilities Engineering Applications Program (FEAP) Work Unit FEAP-EB-FJ1, "Installation Steam Dispatching System." The USAEHSC technical monitor was Satish Sharma, CEHSC-FU-M.

The demonstration was conducted by the Fuels and Power Systems Team (FEP) of the Energy and Utility Systems Division (FE), Infrastructure Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). The principal investigator was Ralph Moshage, CECER-FEP. The team leader is Gary Schanche, CECER-FEP. The division chief is Dr. David M. Joncich, CECER-FE. Chief of the Infrastructure Laboratory is Dr. Michael J. O'Connor, CECER-FL. Thanks go to Yaoxin Qian and Rama Katz for their contribution to this report. The USACERL technical editor was Gordon L. Cohen, Information Management Office.

LTC David J. Rehbein is Commander of USACERL and Dr. L.R. Shaffer is Director.

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# STEAM DISPATCHING CONTROL SYSTEM DEMONSTRATION AT FORT BENJAMIN HARRISON

## 1 INTRODUCTION

### Background

Currently most military district steam heating systems operate by maintaining a constant steam pressure regardless of actual steam demand. This method of operation, while practical, is often the cause of significant energy losses. Energy conservation is a national goal and a practical necessity for the U.S. Army. In accordance with this outlook, researchers at the U.S. Army Construction Engineering Research Laboratories (USACERL) have investigated the Steam Dispatching Control System (SDCS), a control system for reducing energy losses in a distribution system by controlling the steam pressure. Lowering the steam pressure to slightly above the amount needed to meet thermal demand reduces the steam temperature with only slight reductions in steam enthalpy (heat content). Thermal losses at the lower temperature are reduced and leak losses are diminished.

Successful use of SDCS by industry indicated that the system might successfully be applied to Army installation central heating systems. Therefore, based on a feasibility study conducted by the Oak Ridge National Laboratory, the Facilities Engineering Applications Program (FEAP) chose Fort Benjamin Harrison as the first Army demonstration site for this technology.

### Objective

The objective of this project was to demonstrate operation of the Steam Dispatching Control System on a central steam heat distribution system serving an Army installation.

### Approach

The approach to this demonstration followed four specific phases: (1) selection of a candidate site, (2) computer modeling of the site's central heating system to estimate potential savings, (3) design and installation of the dispatching control system, and (4) collection and analysis of operating data to monitor the performance of the system. Using the analysis of this data, SDCS was fine-tuned to produce additional cost and energy savings.

### Scope

In general, the results of this demonstration are applicable to installations with a large central heating plant and a substantial steam distribution system. Boiler fuel is not a critical factor in the level of energy savings achieved.

### Mode of Technology Transfer

It is recommended that information about this technology be presented in a paper at the 1992 Electrical and Mechanical Engineering Conference sponsored by the Office of the Chief of Engineers (OCE), and published in *DEH Digest*. Information about this technology is also being prepared for publication in a *FEAP User Guide*.

## 2 STEAM DISPATCHING CONCEPTS

A study prepared by Oak Ridge National Laboratories (ORNL) has documented the benefits of SDCS, a control system that lowers the steam pressure in the steam distribution system to slightly above the amount needed to meet the system load (McLain and Karnitz, October 1986). Lowering the steam pressure in a distribution system saves energy by reducing heat transfer losses and leak losses.

### Thermal Loss Reduction

Lowering the pressure of saturated steam reduces its temperature, diminishing heat loss in the distribution system while having little effect on the enthalpy (heat content) of the steam (Table 1). Lowering the steam pressure, for example, from 100 psig* to 50 psig results in a steam enthalpy drop of less than 0.9 percent while the reduction in heat transfer losses exceeds 14 percent.

### Leak Loss Reduction

A second benefit of reducing the steam pressure includes savings accrued from the reduction in steam loss from leaks and faulty traps. Considerable savings may be expected due to the reduction of these losses. Steam losses due to leaks are proportional to the square root of the difference between steam pressure and atmospheric pressure (Lilly, February 1987). Equation 1 forms the basis for this comparison:

$$Q = A \times C \times \sqrt{2gh} \qquad \text{[Eq 1]}$$

where Q = steam loss (lb/hr)
A = area of opening (sq in.)
C = discharge coefficient (constant)
g = gravity constant (ft/s$^2$)
h = pressure drop (psig).

Using this relationship under the same conditions as the thermal loss example, pressure reduction frc ' 100 to 50 psig, for example, shows that the decrease in steam loss would be on the order of 29 percent.

In the case of thermal losses, the estimated savings are based on engineering estimates of pipe heat loss coefficients and a technical description of the distribution system layout and operation. Determination of leak loss reduction is not as straightforward, however. The integrity of the steam lines and steam traps can only be determined through a detailed evaluation of the distribution system. Short of this, engineering estimates of the losses are made, and then correlated and adjusted in the modeling phase of a project. Typically, however, experience shows that leak losses account for a majority of the energy losses in a distribution system and hold the greatest potential for savings.

* psig: pounds per square inch gauge. U.S. standard units of measure are used in this report. A table of metric conversion factors may be found on p 38.

Table 1

Typical Conditions for Buried Steam Line*

| Pressure (psig) | Enthalpy (Btu/lb) | Change (%) | Temp. (°F) | Heat Loss (Btu/h-ft) | Change (%) |
|---|---|---|---|---|---|
| 100 | 1189.6 | 0.0 | 337.8 | 259 | 0.0 |
| 75 | 1185.2 | -0.4 | 320.0 | 243 | -6.4 |
| 50 | 1179.0 | -0.9 | 297.6 | 223 | -14.2 |
| 25 | 1169.7 | -1.7 | 267.3 | 196 | -24.7 |

*Source: McLain and Karnitz, October 1986.

## Equipment Components

Control of the steam pressure in a distribution system can be accomplished by regulating the boiler drum pressure or through the use of pressure-reducing valves (PRVs) off of the main steam header in the plant. Generally, wide fluctuations in boiler drum pressure are not desirable, so the use of a PRV is the recommended strategy.

The major components required for this control strategy are the PRV, the control system, and pressure and temperature measuring devices. Figure 1 shows a typical layout of these components for one line.

The PRV is sized to function over the entire range of the expected flow. The equipment layout should allow for isolation of the PRV during repairs or for bypass during an equipment failure. In addition, the PRV must be set to fail in the fully open position.

The control system consists of a self-contained microprocessor-based instrument that continuously controls its process according to a programmed algorithm. This algorithm is based on a control curve developed during the modeling phase. This controller should have the capacity to operate as a PID (proportional integral derivative) controller or in a self-tuning mode. When used in the self-tuning mode, the controller adjusts the values of P, I, and D based on real-time distribution system dynamics. The degree of response is selected by choosing the desired damping and overshoot-to-load ratios. This ability allows SDCS to function optimally during periods of changing system dynamics, such as a major load variation or during seasonal transitions.

Data collection equipment for the system consists of standard, off-the-shelf components for measuring steam pressure, air temperature, and steam flow. Steam flow readings are not required for operation of SDCS, although this information is useful in evaluating and optimizing system operation.

## Technical Considerations

Fort Benjamin Harrison was chosen as the FEAP demonstration site for SDCS due to its location and the characteristics of its distribution system. The heating plant at Fort Harrison consists of three gas/oil-fired water tube boilers capable of generating 190,000 lb/hr (pph) of steam at 100 psig. Natural gas (costing about $3.26/MBtu) is the primary fuel used, with No. 2 oil used as a backup fuel. Seven miles of buried steam lines laid out in three independent networks feed the buildings on the 2500 acre base. The three independent systems are connected to a common header at the heating plant, and are designated as the Alpha, Beta, and Delta lines. The average yearly temperature is 52 °F and the annual number of heating degree-days averages about 5455.

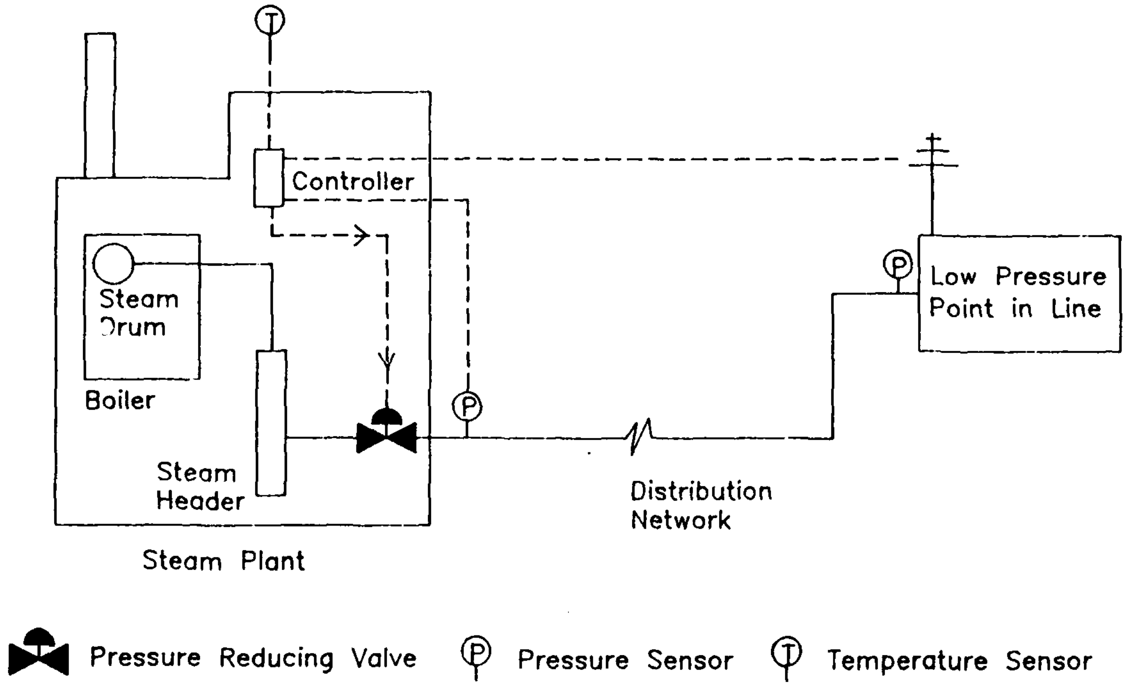


**Figure 1. Steam Dispatching Control System Equipment.**

During modeling and design of a SDCS several critical issues must be addressed. Careful evaluation will ensure that SDCS performs as expected with a minimal negative impact to the end user. Items for evaluation include process load requirements, distribution system steam velocity, steam trap capacities, end user PRV capacity, and PRV impact.

*Process Load Requirements*

Some buildings require steam at a pressure higher than what is needed for the heating load. An example of this at Fort Harrison is the base hospital, which houses a sterilizing unit that requires steam at a pressure of 65 psi or greater to work properly. The SDCS controller curves had to be calculated taking this requirement (and other similar ones) into account.

*Steam Velocity*

Another concern that must be evaluated is the velocity of the steam through the distribution system. Standards taken from the *ASHRAE Handbook* (American Society of Heating, Refrigerating, and Air-Conditioning Engineers 1985) suggest steam velocities of between 8,000 and 12,000 feet per minute (fpm), with a maximum of 15,000 fpm. Equation 2 (Lilly, February 1987) is used to determine the velocity of steam flow through a pipe:

$$V = (3.05 \times Q \times v) \ / \ d^2 \qquad \text{[Eq 2]}$$

where V = velocity (fpm)
Q = flow (lb/hr)
v = specific volume (cu ft/lb)
d = internal pipe diameter (in.).

Based on this relationship, maximum velocities for the Alpha, Beta, and Delta lines at Fort Benjamin Harrison would increase from about 3525, 3950, and 2750 fpm to 6350, 7100, and 4950 fpm, respectively, resulting from a decrease in pressure from 100 psig to 50 psig. The velocity increase is caused by a decrease in the specific volume due to the pressure decrease. The increase in velocity would cause an increase in the pressure drop in the lines due to increased friction. These velocities are well below the recommended ASHRAE limit of 12,000 fpm. Table 2 shows the maximum steam flow and velocity for each line at Fort Harrison, and presents steam velocities for various line sizes and flows.

*Steam Trap Capacity*

Steam trap capacity decreases as the steam pressure is reduced. The existing steam traps must be able to meet the expected capacity at the reduced pressure. As mentioned earlier, a pressure reduction from 100 to 50 psig decreases steam losses by 29 percent; this pressure reduction will also reduce the capacity of the steam traps by 29 percent. Traps that cannot meet the capacity must be replaced. If the steam trap capacity at a lower pressure is not sufficient, condensate will back up into the steam system, causing poor heater performance and increasing component corrosion.

*End User PRV Capacity*

Another concern faced in implementing an SDCS, both in general and in the Fort Benjamin Harrison demonstration in particular, is how to supply adequate heat energy to the buildings at a reduced sendout pressure. Each building on the installation's central heating system is equipped with a pressure-reducing station that has a known capacity at a given inlet pressure. When inlet pressure is reduced, the steam capacity will also decrease. Matching existing maximum steam capacities for each building involves replacing PRVs with larger valves (that is valves with a larger flow coefficient, Cv).

Consider the case where steam pressure is being reduced from 100 to 50 psig. Table 3 shows that the enthalpy of dry saturated steam is 1189 Btu/lb and 1180 Btu/lb for steam pressures of 100 and 50 psig, respectively. Therefore, the maximum amount of heat delivered to the equipment is 99 percent of the original maximum value, but the temperature is approximately 40 °F lower.

To determine the new, appropriate Cv, the Cv of the existing PRV must be known. (This value is available from the valve manufacturer.) The capacity is determined as follows:

$$Q = 2.1\, C_v \left(\sqrt{P_1 - P_2}\right)\left(\sqrt{P_1 + P_2}\right) \qquad \text{[Eq 3]}$$

**Table 2**

**Maximum Steam Velocities**

| Lines | Pipe Diameter (inches) | Maximum Steam Flow (lb/hr) | Maximum Steam Velocity @ 100 psi (fpm) | Maximum Steam Velocity @ 50 psi (fpm) |
|---|---|---|---|---|
| Alpha | 8 | 20,000 | 3527 | 6338 |
| Beta | 10 | 35,000 | 3950 | 7099 |
| Delta | 12 | 35,000 | 2743 | 4930 |

Table 3

Saturated Steam: Temperature Table

| | Specific Volume | | | Enthalpy | | |
|---|---|---|---|---|---|---|
| Temp •F $T$ | Press. psig $P$ | Saturated Liquid $V_f$ | Saturated Vapor $V_g$ | Saturated Liquid $h_f$ | Saturated Evap. $h_{fg}$ | Saturated Vapor $h_g$ |
| 290 | 42.83 | 0.017352 | 7.467 | 259.44 | 917.8 | 1177.2 |
| 300 | 52.28 | 0.017448 | 6.472 | 269.73 | 910.4 | 1180.2 |
| 310 | 62.94 | 0.017548 | 5.632 | 280.06 | 903.0 | 1183.0 |
| 320 | 74.90 | 0.17652 | 4.919 | 290.43 | 895.3 | 1185.8 |
| 330 | 88.30 | 0.017760 | 4.312 | 300.84 | 887.5 | 1188.4 |
| 340 | 103.23 | 0.017872 | 3.792 | 311.30 | 879.5 | 1190.8 |

where $Q$ = flow in lb/hr (capacity)
$P_1$ = inlet pressure (psia*)
$P_2$ = outlet pressure (psia).

After the maximum capacity is determined for existing conditions, the new Cv can be easily found. As a precautionary measure, the maximum capacities that were calculated in this manner were compared with condensate measurements at each building. The calculated maximum capacities using the valve Cv proved to be the most conservative and were therefore employed (Lilly, February 1987).

*PRV Impact*

One problem with the Saturated Steam Model used by SHDP (see Chapter 3, "Site Modeling") is the effect of the PRVs on the steam. The steam becomes superheated as it passes through the PRV, returning to the saturated state some distance down the line. An example using worst-case conditions was compiled to study the effect of various pipe sizes and steam loads on this distance.

It was assumed that the input to the PRV was 100 psig saturated steam and the output was 50 psig superheated steam at a temperature of 313 °F (no enthalpy drop through the PRV). The model in Figure 2 was used to calculate the length of pipe needed for the steam to return to its saturated state at the lower pressure.

To determine the length of pipe that a given quantity of steam would flow through to reach a predetermined temperature and pressure, the following heat balance was used:

Heat lost by steam = Heat gained by ambient.

The pipe was assumed to be well insulated, and no frictional losses were taken into account. Substituting appropriate variables, it was found that:

*psia: pounds per square inch absolute.

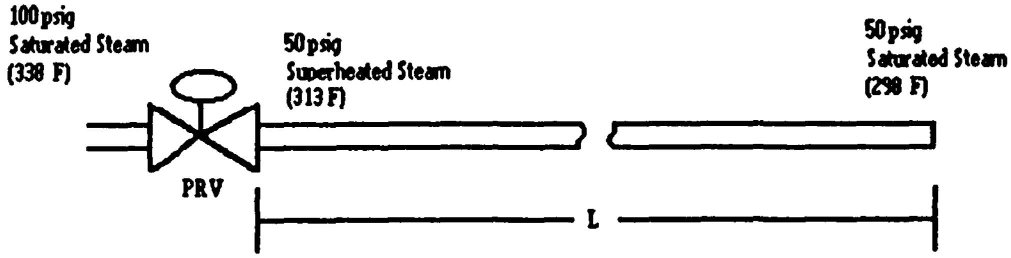


**Figure 2. Model for Pipe Length Calculation.**

$$PHLC \times (T_1 - T_2) \times L = Flow \times (T_{ave} - T_{amb}) \times cp_{ave} \qquad \text{[Eq 4]}$$

where PHLC = pipe heat loss coefficient (Btu/hr-ft-°F)
$T_1$ = initial steam temperature (°F)
$T_2$ = final steam temperature (°F)
L = pipe length (ft)
Flow = steam flow (lb/hr)
$T_{ave}$ = average steam temperature (°F)
$T_{amb}$ = ambient air temperature (°F)
$cp_{ave}$ = average specific heat of steam (Btu/lb-°F).

This equation was then solved for pipe length:

Table 4 shows the results of the velocity and pipe length calculations from these equations for a variety of pipe sizes and steam flows. From Table 4 it can be seen that this effect of the PRV on the steam properties can be ignored for most calculations. The values for the physical properties of steam are from the *ASHRAE Handbook* (ASHRAE 1985) and *CRC** *Handbook* (Bolz and Tuve, eds., 1973). Pipe heat loss coefficients were found in the Steam Heat Distribution Program User's Manual (Miller and Waserman, August 1989).

### Advantage of SDCS Over Fixed Pressure

Having looked at its benefits and concerns, another way to address questions about the viability and necessity of a system such as SDCS is to ask why a facility would require such a system—why not simply lower the pressure to a fixed value for different seasons? The reason is that if a facility fixes the pressure at a constant value, that pressure would have to supply enough steam at all possible loads during that

* CRC: Chemical Rubber Company.

## Table 4

### Superheated Steam to Saturated Steam Line Length Requirements

Pressure Drop from 100 PSIG Saturated Steam to 50 PSIG

| | | | |
|---|---|---|---|
| ambient temperature ( F) | 50.000 | | |
| Saturated Steam Properties: | | Superheated Steam Properties: | |
| steam pressure (psig) | 50.000 | steam pressure (psig) | 50.000 |
| steam temperature ( F) | 298.000 | steam temperature ( F) | 313.000 |
| specific heat (Btu/lb.- F) | 0.540 | specific heat (Btu/lb.- F) | 0.522 |
| density (lb./cu.ft.) | 0.150 | density (lb./cu.ft.) | 0.140 |

| | steam flow (lb./hr.): | 50000 | | 25000 | | 10000 | | 2000 | | 500 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| diameter | heat loss coefficient of | velocity | length | velocity | length | velocity | length | velocity | length | velocity | length |
| (inches) | pipe (Btu/hr.-ft.- F) | (fpm) | (feet) | (fpm) | (feet) | (fpm) | (feet) | (fpm) | (feet) | (fpm) | (feet) |
| 1 | 0.39 | ********** | ********** | ********** | ********** | ********** | ********** | ********** | ********** | 10524 | 40 |
| 1.5 | 0.59 | ********** | ********** | ********** | ********** | ********** | ********** | ********** | ********** | 4677 | 26 |
| 2 | 0.72 | ********** | ********** | ********** | ********** | ********** | ********** | 10524 | 87 | 2631 | 22 |
| 2.5 | 0.83 | ********** | ********** | ********** | ********** | ********** | ********** | 6735 | 75 | 1684 | 19 |
| 3 | 0.99 | ********** | ********** | ********** | ********** | ********** | ********** | 4677 | 63 | 1169 | 16 |
| 3.5 | 1.12 | ********** | ********** | ********** | ********** | 17181 | 278 | 3436 | 56 | 859 | 14 |
| 4 | 1.24 | ********** | ********** | ********** | ********** | 13154 | 251 | 2631 | 50 | 658 | 13 |
| 5 | 1.51 | ********** | ********** | ********** | ********** | 8419 | 206 | 1684 | 41 | 421 | 10 |
| 6 | 1.63 | ********** | ********** | 14616 | 478 | 5846 | 191 | 1169 | 38 | 292 | 10 |
| 8 | 2.07 | 16443 | 753 | 8221 | 376 | 3289 | 151 | 658 | 30 | 164 | 8 |
| 10 | 2.52 | 10524 | 619 | 5262 | 309 | 2105 | 124 | 421 | 25 | 105 | 6 |
| 12 | 2.82 | 7308 | 553 | 3654 | 276 | 1462 | 111 | 292 | 22 | 73 | 6 |
| 14 | 2.94 | 5369 | 530 | 2685 | 265 | 1074 | 106 | 215 | 21 | 54 | 5 |
| 16 | 2.97 | 4111 | 525 | 2055 | 262 | 822 | 105 | 164 | 21 | 41 | 5 |

period. To provide adequate steam flow throughout a season, the pressure would be set to supply an adequate load at the lowest temperature expected during the period. This approach may be fine during the summer when there is no heating load, but during the cooler months, considerable savings can be achieved using SDCS on a daily basis. With temperatures varying 20 to 30 degrees on a given day, the supply pressure required to meet the load could vary greatly.

A typical winter day at Fort Harrison, for example, could have a low of 15 °F and a high of 35 °F. The required pressures for the Alpha, Beta, and Delta lines at 15 °F are 55, 65, and 95 psig respectively (see "Selection of Control Points" in Chapter 3). Even if the facility were using a fixed pressure system and changing the pressure daily, 55, 65, and 95 psig would be the set points. At 35 degrees ambient temperature, however, the three lines require pressures of 40, 55, and 81 psig respectively—all lower than that day's setpoints. In some cases, the actual practice of changing a fixed pressure on a daily basis is not practical. The pressures may be set for a duration of 1 month or longer rather than adjusted daily. This would require the pressure to be set at a value that would meet the load at the lowest temperature expected during that time period. If temperatures varied significantly during that period, the loss in possible savings (compared to using a control system) could likewise be significant.

# 3 DEMONSTRATION PROJECT

## Site Description

Fort Benjamin Harrison was chosen as the FEAP demonstration site for SDCS due to its location and the characteristics of its distribution system. Fort Harrison is located near Indianapolis, Indiana. The installation is a U.S. Army Soldier Support Center and houses the Army Finance Center. As noted previously, 7 miles of buried steam lines feed the buildings on the 2500 acre base. The average yearly temperature is 52 °F, and the annual number of heating degree-days averages about 5455.

The heating plant at Fort Harrison consists of three water tube boilers capable of generating 190,000 lb/hr (pph) of steam at 100 psig. Boiler 1 is an old gas-fired unit manufactured by Keystone. Its maximum capacity is 60,000 lb/hr, but it is in poor condition and rarely used. Boilers 2 and 3 are new units manufactured by Nebraska. Installed in 1989, they have maximum capacity ratings of 50,000 and 80,000 lb/hr respectively. Natural gas is the primary fuel used, with No. 2 oil used as a backup fuel.

## Distribution System

The steam distribution system at Fort Harrison consists of approximately 7 miles of steam lines laid out in three independent networks. As noted previously, the three independent systems are connected to a common header at the heating plant, and are designated as the Alpha, Beta, and Delta lines. Figure 3 shows the layout of the heating plant, including the location of PRVs, pressure transducers, and the control panel. The Alpha line is a short line feeding Building 1, the large finance center. The Beta line feeds the buildings north and northwest of the heating plant. These consist mainly of Series 400, 500 and 600 buildings. The Delta line feeds the buildings to the east and northeast, including Series 300 and 400 buildings. Figure 4 shows a schematic of the Fort Harrison steam distribution system.

The Alpha line, Delta line, and portions of the Beta line are preinsulated, buried, Schedule 40 carbon steel pipe. The nominal pipe diameters are shown in Figure 4. A large portion of the distribution system is at least 7 years old. A shallow trench system was installed on the 8 in. portion of the Beta line in the summer of 1990, and the Series 600 buildings were added to the shallow trench system in the summer of 1991. Figure 5 shows the layout of the three main lines and the location of the remote sensing units that collect data for SDCS.

## Operating Costs and Parameters

The boilers at Fort Harrison currently burn natural gas at $3.26/MBtu and produce steam at 100 psig. Boiler feedwater is preheated to 225 °F. In 1990, 388,195 MBtu of natural gas were used to produce 326,084 MBtu of steam. The average boiler efficiency was calculated at 84 percent. The heating value of the natural gas was 950 MBtu/mcf (Citizens Gas & Coke Utility of Indiana).

Table 5 shows fuel consumption and steam production data for January 1990 through December 1991.

Data pertaining to Fort Harrison building use, age, floor area, and the steam distribution system were obtained from the installation Facilities Engineering Office. These data were used with other data from the U.S. Air Force Environmental Technical Applications Center (ETAC) and building energy-use correla-

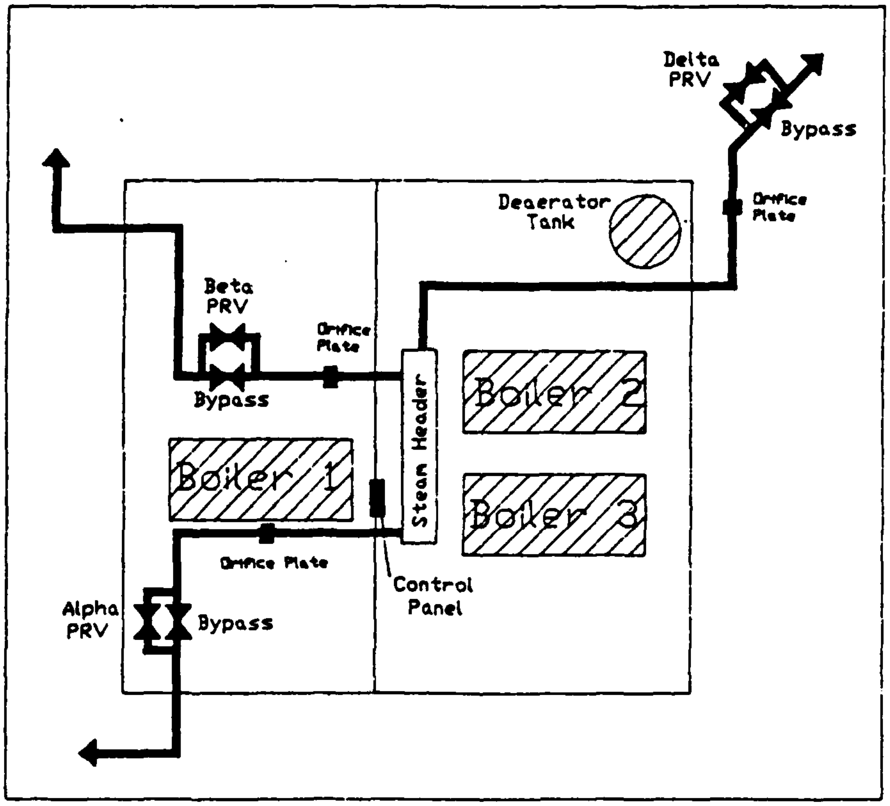


**Figure 3. Fort Harrison Heating Plant Layout.**

tions to estimate the amount of energy used at the base. The useful energy of the steam was estimated at 1046.2 Btu/lb, based on a saturated steam supply pressure to the building of 15 psig and a condensate return temperature of about 150 °F (McLain and Karnitz 1986). Also, based on the regression of the historical steam production data, it was assumed that the heating balance point temperature was 65 °F.

## Site Modeling

Before the demonstration, a model of the steam distribution system at Fort Harrison was developed using the Steam Heat Distribution Program (SHDP), a pressure-flow thermal efficiency computer program for modeling steam distribution systems (Miller and Wasserman, August 1989). See Appendix A for SHDP input and output files. Models for building steam demand were created using studies by Northeast Utilities and USACERL. Functions relating outdoor temperature and required steam pressure were developed from these models. These models were reasonably accurate when used on large groups of buildings, but the model broke down for the large Finance Center building, and had to be adjusted using data taken during the demonstration. This modeling exercise showed potential estimated savings from heat loss reductions equalling $42,000 per year, or 10.8 x $10^9$ MBtu/yr.

### *Building Load*

One of the most important inputs needed for an SHDP model is the thermal energy use, or heat load, for each building in the distribution network. The heat load can be determined through various analysis technologies or procedures. Common tools include the Building Loads Analysis and System

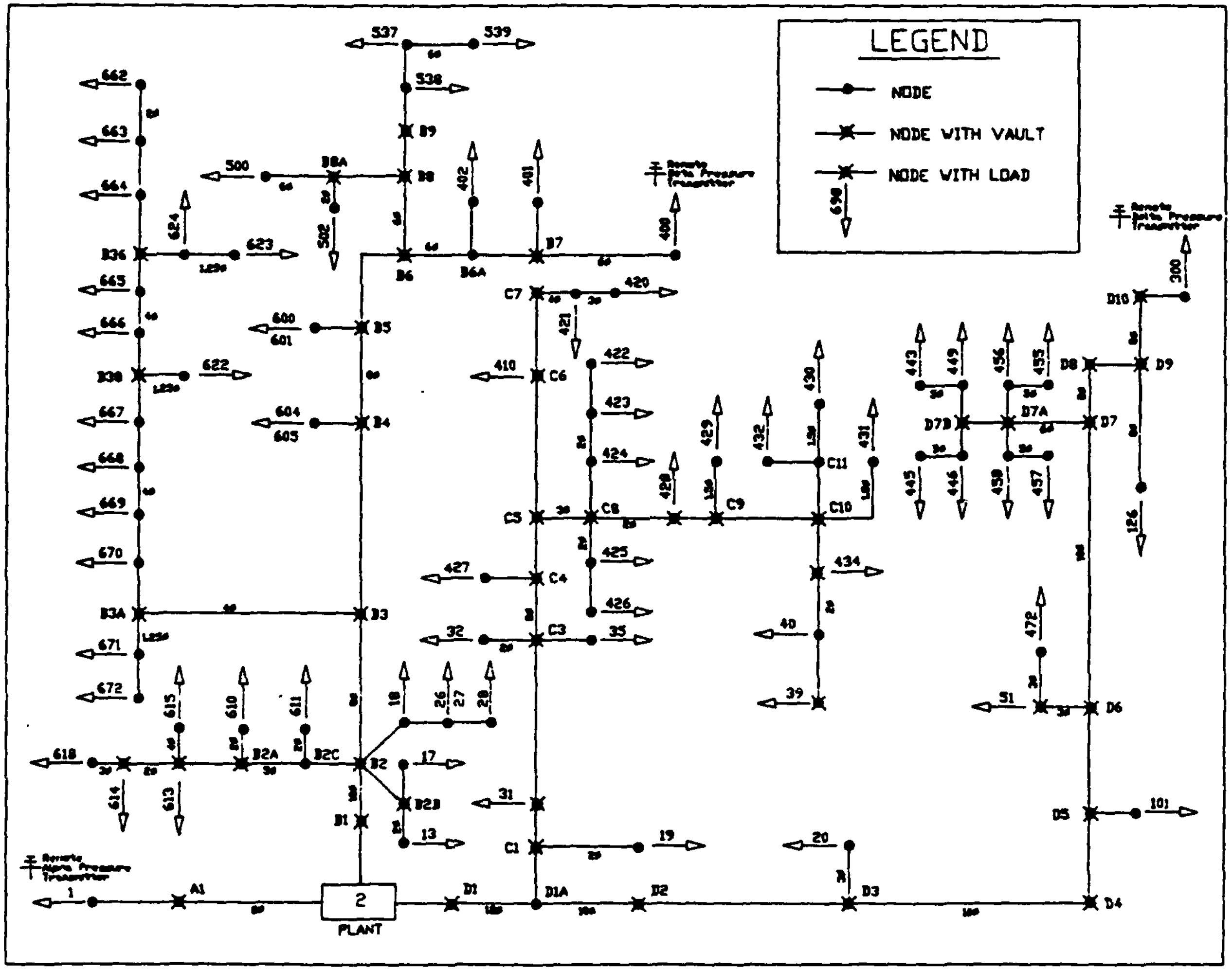


Figure 4. Schematic of Fort Harrison Steam Distribution System.

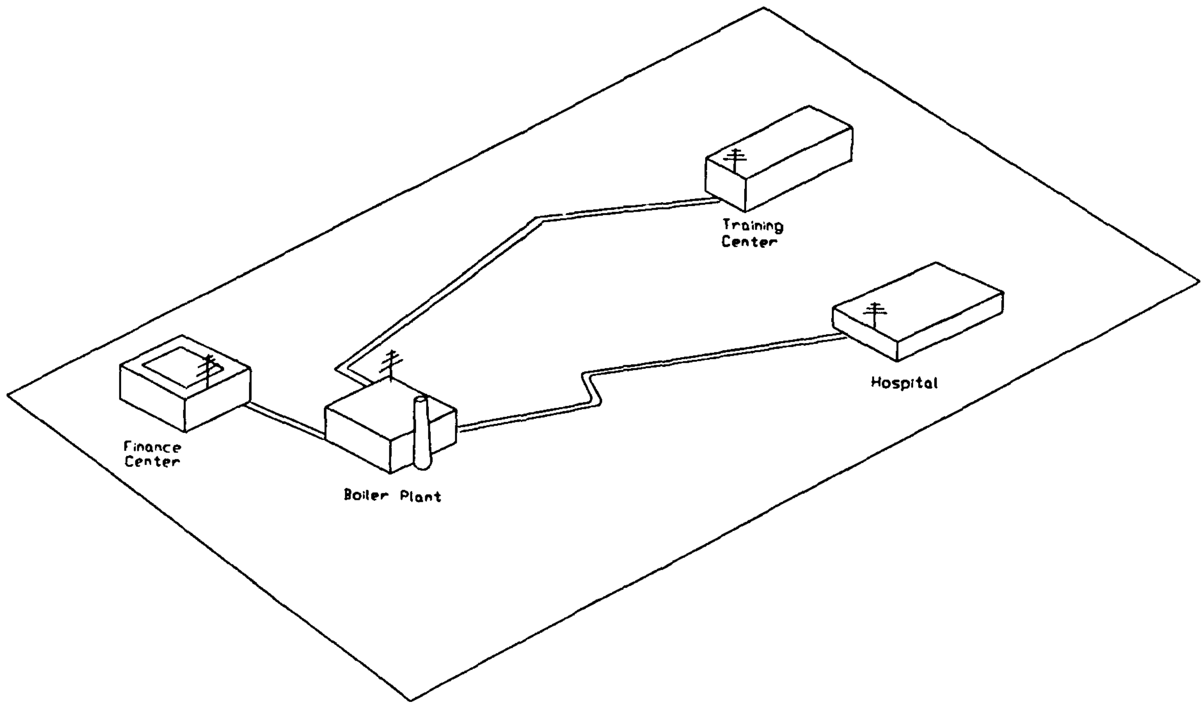


**Figure 5. Location of Remote Sensing Units.**

Thermodynamics (BLAST) program, developed by USACERL, DOE II, developed by the U.S. Department of Energy, and various manual methods developed by ASHRAE. However, these techniques can be very time-consuming when analyzing an entire installation. To work around this problem, USACERL developed an estimating procedure based only on building function, building floor area, and outside temperature. Linear correlations by building function were developed, based on study of building energy metering data from several Army installations. For each type of building a corresponding daily thermal energy consumption equation can be expressed in the form of:

$$E = a + (b \times HDD) \qquad \text{[Eq 6]}$$

where E = daily thermal energy consumption (Btu/sq ft/day)
HDD = daily heating degree-days
a = constant representing nonheating loads at zero HDD (hot water, cooking, etc.)
b = variable heating load dependent on HDD.

Table 6 shows the building categories available. Most of the buildings at Fort Harrison are more like commercial and residential buildings, and are appreciably more energy-efficient than typical Army family housing units. Therefore, the daily thermal energy balance equation used for the SHDP model was derived from data in studies by USACERL and the utility group Northeast Utilities (Sliwinski and Elischer, August 1983; Xenergy Inc., January 1986). The zero HDD parameter (a) was taken from the USACERL study. The variable energy usage parameter (b) was taken from the Northeast Utilities study after preliminary modeling showed the USACERL values for b to be too high. As is shown in the next section, "Model Verification," these data accurately characterize the daily thermal energy usage for Fort

**Table 5**

**Fort Harrison Fuel Consumption and Steam Production (January - August 1990)**

| Month | Steam 1000 lbs | Gas M.C.F | Steam MBtus | Gas MBtus |
|---|---|---|---|---|
| JAN 90 | 39891 | 50263 | 39647665 | 47749850 |
| FEB 90 | 37309 | 42594 | 37081415 | 40464300 |
| MAR 90 | 35784 | 41898 | 35565718 | 39803100 |
| APR 90 | 27905 | 31985 | 27734780 | 30385750 |
| MAY 90 | 16584 | 21819 | 16482838 | 20728050 |
| JUN 90 | 18340 | 21142 | 18228126 | 20084900 |
| JUL 90 | 19290 | 23415 | 19172331 | 22244250 |
| AUG 90 | 15910 | 21509 | 15812949 | 20433550 |
| SEP 90 | 12381 | 16830 | 12305476 | 15988500 |
| OCT 90 | 19598 | 24831 | 19478452 | 23589450 |
| NOV 90 | 27031 | 32037 | 26866111 | 30435150 |
| DEC 90 | 40389 | 48200 | 40142627 | 45790000 |
| JAN 91 | 49288 | 57395 | 48987343 | 54525250 |
| FEB 91 | 38413 | 44356 | 38178681 | 42138200 |
| MAR 91 | 31087 | 35919 | 30897369 | 34123050 |
| APR 91 | 19786 | 28011 | 19665305 | 26610450 |
| MAY 91 | 17508 | 22143 | 17401201 | 21035850 |
| JUN 91 | 18288 | 22617 | 18176443 | 21486150 |
| JUL 91 | 19877 | 22025 | 19755750 | 20923750 |
| AUG 91 | 19585 | 23488 | 19465532 | 22313600 |
| SEP 91 | 13454 | 14971 | 13371931 | 14222450 |
| OCT 91 | 13914 | 17890 | 13829125 | 16995500 |
| NOV 91 | 29883 | 36217 | 29700714 | 34406150 |
| DEC 91 | 35330 | 41970 | 35114487 | 39871500 |
| Total | 616825 | 743525 | 613062368 | 706348750 |

Harrison. HDD data was obtained from ETAC. Steam production data were acquired from the central heating plant operating logs, and building area measurements were obtained from the Real Property Detail Report for Fort Harrison.

Building number, use, and floor area are compiled in Appendix B. As noted above, studies by USACERL and by Northeast Utilities were used to develop a linear correlation between building energy demand and heating degree-days for each type of building found on the installation. The predicted intercept and slope were used along with the floor area data to calculate an intercept and slope for each building. See Appendix B (McLain and Karnitz 1986).

*Model Verification*

The calculated heating load for each of the three lines was plotted with the actual steam flow versus the outdoor temperature. The models for the Beta and Delta lines matched up very well, both having

almost the identical slope as the plot of actual steam flow data (see Figures 6 and 7). The offset between the model flow and the actual steam flow depicts the losses due to heat loss and steam leaks.

The model for the Alpha line load consisted only of the Finance Center. A USACERL study indicated that the error in the model heating load equations increased as fewer buildings were involved (Sliwinski and Elischer, August 1983). The slope for the finance center required an adjustment from 332.1 lb/hr-deg F to 116.0 lb/hr-deg F. The new slope was calculated by taking a linear regression of data taken from the Alpha line (Figure 8). The small offset between the regression line and the actual data depicts the low losses from this line, which are attributable to the shortness of the line between the heating plant and Building 1.

*Selection of Control Points*

After the models were corrected, the low-pressure point in each subsystem was located. Initially, the remote pressure was going to be used to control the PRV. The setpoint would be held at a constant value for all temperatures. If the low-pressure point in the lines was kept at the lowest allowable pressure, then the pressure along the rest of the line would be adequate. Two problems arose from this method, however. One problem was the time delay in the response of the system: adding any time delay made the control system less stable. The other problem involved the reliability of the data transmitting equipment: many problems encountered in the demonstration were related to the remote data collection equipment. Because of these constraints, control of the PRVs was based on the line pressure readings at the boiler plant.

These locations (low-pressure points in the subsystems) were kept at the minimum allowable pressure. The steam pressure reaching the base hospital, for example, had to be sustained at a minimum of 65 psi. The required line pressure at the plant, used as the pressure setpoint, was calculated from the

**Table 6**

**HEATLOAD Categories**

| Building Type | a | b |
|---|---|---|
| Family Housing | 113.50 | 10.50 |
| Barracks, pre-1966 | 130.50 | 10.53 |
| Barracks, post-1966 | 81.90 | 7.40 |
| Barracks, modular | 295.90 | 10.53 |
| Administration/Training | 75.70 | 7.02 |
| Dining Facilities | 241.90 | 0.00 |
| Medical/Dental | 254.40 | 11.41 |
| Production/Maintenance | 138.25 | 10.53 |
| Field Houses and Gymnasiums | 73.70 | 4.39 |
| Commissary | 147.00 | 7.02 |
| Storage Buildings | 35.70 | 10.53 |
| Theater/Rec Center | 231.50 | 5.25 |
| NCO/Officers Club | 231.501 | 8.75 |

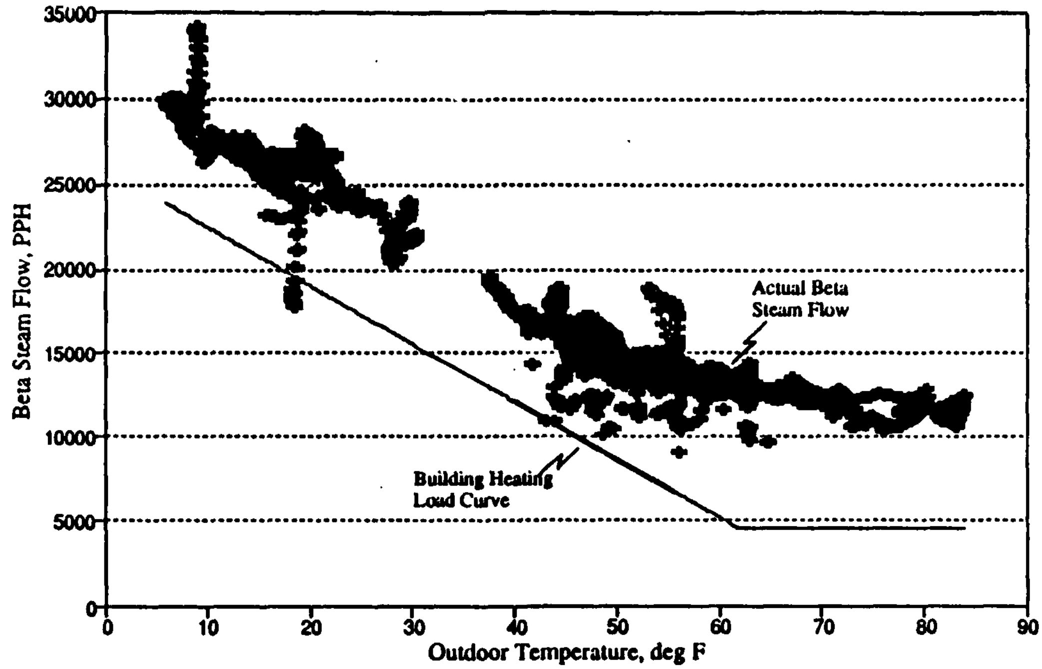


**Figure 6. Model for Beta Line Load.**

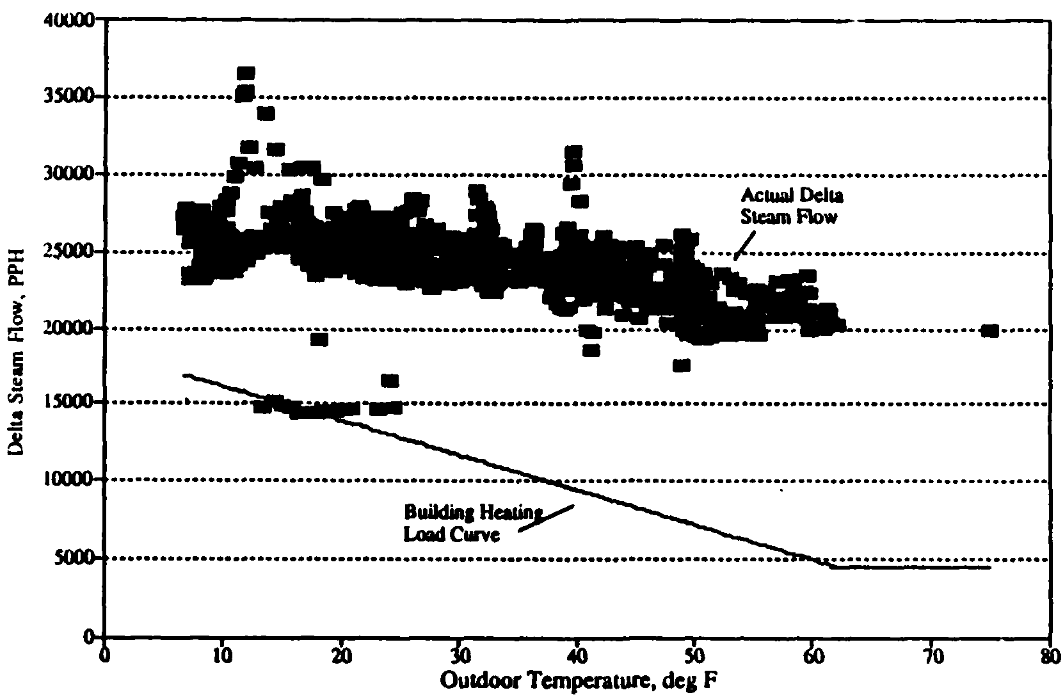


**Figure 7. Model for Delta Line Steam Load.**

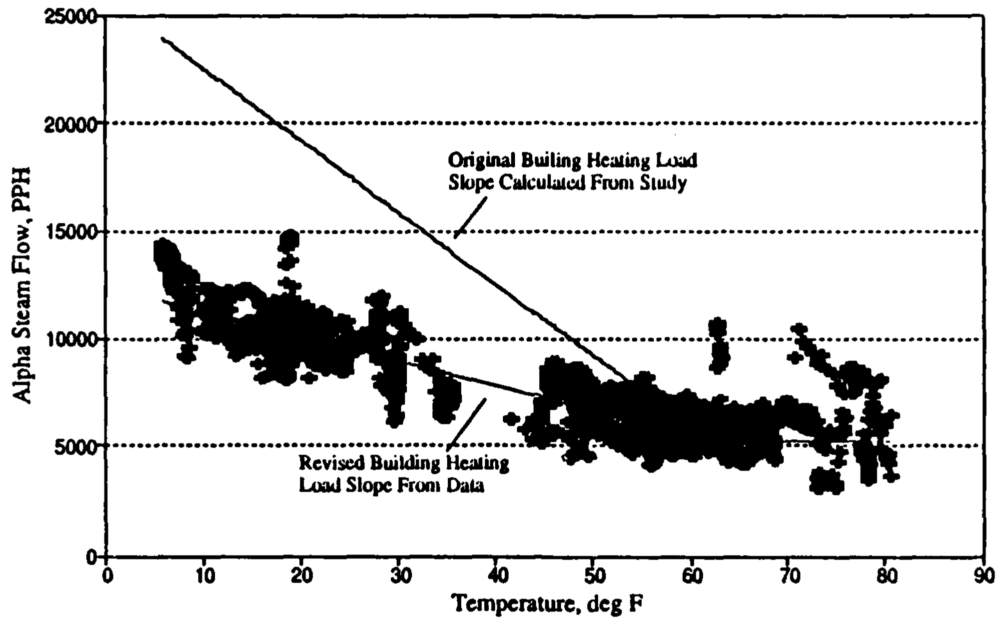


**Figure 8. Model for Alpha Line Steam Load.**

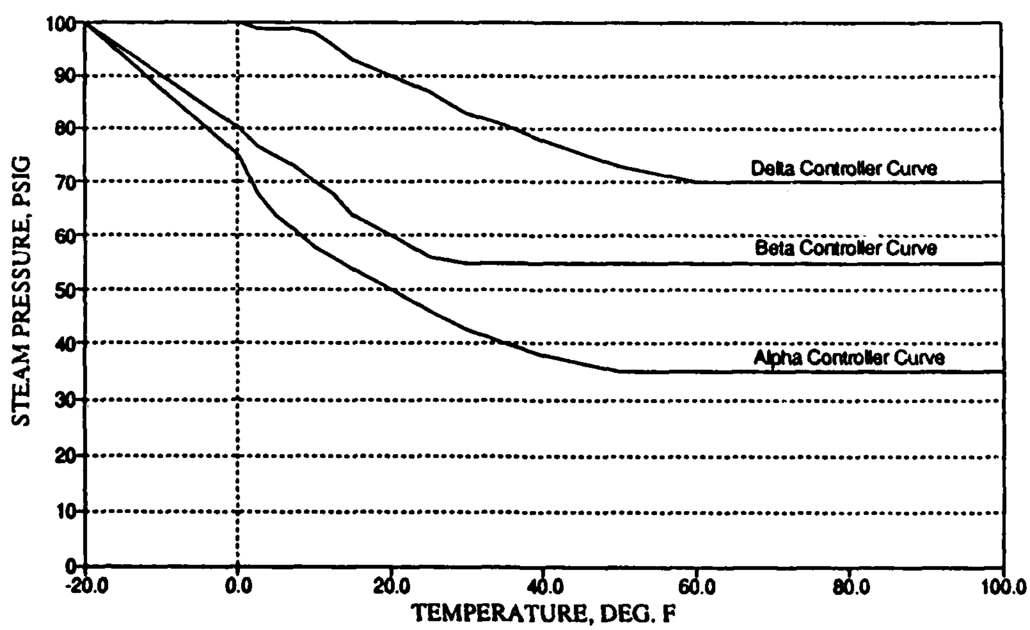


**Figure 9. Controller Set Point Curves for Alpha, Beta, and Delta Lines.**

model using SHDP. This procedure was repeated for four different temperatures—0, 25, 40, and 59 °F—and the control curve was derived from these points (Figure 9). The design temperature for Indianapolis was -2 °F. These original curves were very conservative estimates.

## Equipment

Appendix C contains specification details and instrumentation configuration parameters for the equipment discussed below.

### *PRV*

Fisher Controls Company PRVs were used for reducing the steam pressure from 100 psig to a set point as low as 25 psig. Specifications for the necessary three valves were acquired from the Fisher Control Company *Control Valve Specification* sheets. The PRVs use Fisher Controls type 3590 electro-pneumatic valve positioners to convert the controller signal from a 4-20 milliamp (ma) electrical signal to a pneumatic output signal.

### *Controllers*

The Foxboro 761 Series Single-Station Micro Plus controller was used for the control system. This controller is a self-contained microprocessor-based instrument that continuously controls its process according to its programmed algorithm. This controller can function either in PID mode or in a self-tuning ("EXACT") mode. When not programmed to run in EXACT mode, the controller functions like any PID controller. However, when the 761 is in EXACT mode, the controller adjusts the values of P, I, and D based on real-time dynamics. The user selects the degree of response by choosing the desired damping and overshoot-to-load ratios.

The 761 controller allows two frequency inputs; four 4-20 ma, 10-50 ma, or 1-5 V analog inputs; a 25 V direct current (DC) power supply that can power one or two transmitters; and two contact inputs. It has two analog outputs—a 4-20 ma control output and a 1-5 V auxiliary output. There are also two contact outputs that can be programmed to represent any one of the signals on the Boolean logic gate list.

### *Temperature Transmitter*

A Foxboro Model E94 Temperature Transmitter was used to sense the outdoor temperature. This two-wire transmitter contains a platinum Resistance Temperature Detector (RTD) and outputs a 4-20 ma signal. Its operating range is from -40 °F to +180 °F. It is powered by a DC power supply ranging from 12.5 to 50 V. It has both zero and span adjustments, and is accurate to within 0.15 percent of span or 0.08 °C, whichever is greater. The repeatability and deadband of this transmitter are 0.05 percent of span.

### *Uninterruptible Power Supply*

An uninterruptible power supply (UPS) is needed to provide a constant voltage to the controllers. Line voltages in power plants are typically very noisy. An interruption in power to the controllers would interrupt the output signal to the PRV's. The PRV's are designed to fully open when they lose the output signal. This could result in a loss of boiler pressure possibly shutting down the boiler. At Fort Harrison a Mesta UPS was installed. It provided a very fast switching time and delivered a clean supply voltage to all of the equipment in the control panel. (A smaller model can be used if data acquisition equipment is not installed.)

*Data Collection Equipment*

Autograph 800 Data Logger. Data was collected using an Acurex Autograph 800 data logger. The data logger used was configured to collect up to 15 digital input channels, 20 analog input channels, and 15 channels for RTD inputs. It was programmed to collect data every 30 seconds and average those readings every 15 minutes. The averages were stored in the data logger's memory. The unit could store 2 weeks of data and was capable of downloading the data to USACERL via a modem.

Flow Totalizers and Orifice Plates. The Foxboro Model 75TUA Flow Totalizer was used to calculate steam flow in the three lines. It is a single loop, microprocessor-based instrument for calculating accurate flow rate measurements. Foxboro Model 843 differential pressure (D/P cell) transducers measured the pressure drop across an orifice plate. The accuracy and repeatability of this model are within 0.25 percent of span, and it has both zero and span adjustments. The flow was then calculated using a function based on the physical characteristics of the steam line, the orifice plate, and the steam. The flow was converted to a 4-20 ma signal and retransmitted by the totalizer across a 250 ohm resistor at the terminal board. From there it was measured by an Autograph 800 data logger.

Foxboro OP-FTT concentric bore orifice plates made of 316 stainless steel were used in this demonstration. Typical accuracy of the orifice plates and transmitters is 1 to 2 percent of the upper-range value.

Pressure Transmitters. Foxboro Model 841 Electronic Gauge Pressure Transmitters were used for all steam pressure measurements. These transmitters convert a 0-100 psig pressure reading into a proportional 4-20 ma signal. A supply voltage of 12.5 to 36 volts DC may be used to power the transmitter. Its accuracy is 0.25 percent of span, with repeatability of less than 0.1 percent. It has both zero and span adjustments.

Strip Chart Recorders. Foxboro Model E20-I electronic chart recorders were used to provide the status of various process control signals (i.e., local and remote pressures, outdoor temperatures, and steam flows). The model E20-I accepted 4-20 ma input signals across a 500 ohm input resistor.

Remote Data Transmission Equipment. An Intrac 2000 two-way radio system was used to transmit the remote pressures back to the controllers in the plant. The remote unit consists of an analog-to-digital converter module, an encoder module, and a two-way radio module. This modular system converts the 4-20 ma pressure signal from analog to digital, and adds an address to the signal. The signal is then encoded and broadcast to the central receiving unit using a VHF* radio signal. The central unit consists of a two-way radio module, a decoder module, and a digital-to-analog converter module for each controller. At the plant this signal is received, decoded, and a 4-20 ma signal is generated and transmitted to the controller corresponding to the correct address. Analog values are transmitted from the remote site as soon as they deviate by a fixed amount. The Intrac 2000 system could also be configured to poll the remote radio sites at a fixed time interval.

## Equipment Cost

Table 7 is an estimate of the construction costs for installation of the SDCS at Fort Harrison. Table 8 lists the actual construction costs.

The cost of design for SDCS was $15,493. The estimated costs for the mechanical and electrical materials and labor were $65,317 and $70,000 respectively. The actual cost for materials and labor were $88,081 and $57,339. The total cost was $160,913, of which $22,049 was used for the radio equipment.

*VHF: very high frequency.

**Table 7**

**Estimated Construction Costs***

| Quantity | Equipment Item | Material Cost |
|---|---|---|
| 6 | Pressure Transmitter | 2460 |
| 3 | Orifice Plates | 834 |
| 3 | Orifice Flanges | 2738 |
| 3 | Pressure Indicating Controller | 5550 |
| 3 | Differential Pressure Transmitter | 1650 |
| 3 | Steam Flow Indicator/Totalizer | 2925 |
| 1 | Temperature Element and Transmitter | 570 |
| 2 | 6 Inch Pressure Regulating Control Valves | 10850 |
| 1 | 4 Inch Pressure Regulating Control Valve | 3405 |
| 1 | 12 Inch Gate Valve 300# Flanged | 2543 |
| 1 | 10 Inch Gate Valve 300# Flanged | 1750 |
| 5 | 8 Inch Gate Valves 300 # Flanged | 6080 |
| 2 | 6 Inch Gate Valves 300# Flanged | 1514 |
| 6 | 12 Inch Flanges 300# Raised Face | 864 |
| 6 | 10 Inch Flanges 300# Raised Face | 756 |
| 6 | 8 Inch Flanges 300# Raised Face | 408 |
| 6 | 3/4 Inch Globe Valves | 120 |
| 6 | Pressure Indicators | 300 |
| 1 | Radio Frequency Data Transmission System (3 remote sites transmitting to boilerhouse) | 15000 |
| 1 | Control Panel | 5000 |
| | Material Subtotal | 65317 |
| Installation (as per quotation from Freyn Brothers, Inc., Indianapolis, IN - represented by Larry Brooks) | | 70000 |
| Contractor Overhead and Profit (10%) | | 13530 |
| | Total Project Cost | 148830 |

* Includes no contingency or design costs.

Table 8

Actual Construction Costs

| | |
|---|---|
| Design | 15493 |
| Mechanical/Electrical Materials | 88081 |
| Labor | 57339 |
| Final Installed Cost | 160913 |

This equipment was used mainly to acquire data for the demonstration, and is not essential to the operation of SDCS. Not including the radio equipment, the average cost per line of SDCS at Fort Harrison was about $47,000.

## System Operation

Figure 10 shows the performance of SDCS on the Alpha line pressure during the period from February 16 to 22, 1991. The local pressure is adjusted according to an equation based on the outside temperature (see control curves in Figure 9). A large variance in temperature can be seen over this 1-week period, with temperatures ranging from 17 to 59 °F. The disturbance in the Alpha steam pressure on February 20 was due to a boiler shutdown.

### *System Response With SDCS*

Figure 11 illustrates the impact of operating a distribution system at a reduced steam pressure. When steam pressure in the Beta line was increased from 56 psig to 95 psig during a period of stable temperature, the steam flow increased from approximately 12,300 pph to 13,800 pph. Since ambient conditions did not change significantly during this period, the increase in steam flow can be attributed to increased leak and thermal losses. The perturbations in the steam flow after the increase were due to maintenance on a feedwater valve. It is clear that a significant reduction in thermal energy losses can be realized through implementation of a system such as SDCS. The maximum possible reduction in steam pressure energy savings is initially determined through computer modeling and then verified through actual operation of the system.

Figure 12 shows the response of the control system to a 25 percent step decrease in the Beta steam flow. The initial pressure is 56 psi—the setpoint—before rising to 63 psi during the step decrease, then returning to the setpoint in approximately 12 minutes. The damped response does not overshoot the setpoint and the steam flow remains relatively constant during the pressure reduction. During this time period the temperature rose slightly, dropping the setpoint to 55 psi.

### *Condensate Return System*

In terms of overall systems responses, the condensate return system was adversely impacted by the SDCS in this project demonstration. The main problem reported dealt with excess condensate in the steam lines and heating equipment and was not evident until the SDCS had been fully functional for an entire heating season. The excess condensate buildup was a result of the inability of the steam traps to effectively remove condensate at lower steam pressures. As discussed earlier (see "Technical Considerations" in Chapter 2), the capacity of the steam traps is reduced as the steam pressure is reduced.

A preliminary evaluation, conducted before the installation of SDCS at Fort Harrison, indicated that the existing steam traps had adequate capacity at the reduced steam pressures used by the SDCS. This

conclusion was based on idealized conditions, however, and failed to take into account the impact of SDCS on the entire condensate return system. As discussed previously in "Technical Considerations," solutions to the problem of excess condensate buildup involve the replacement of steam traps and possible modifications to the operation of the condensate return system. Further studies at Fort Harrison will be made to better anticipate and solve problems of this nature.

### Operator Training

An important lesson learned in the demonstration project was that boiler plant operators should be included in the design and installation of the equipment from the start. It is essential that operators feel comfortable with the design of the system so they can make repairs and adjustments as needed. Wiring diagrams, instrument specification sheets, and a concise list of startup and shutdown procedures are very useful as training aids.

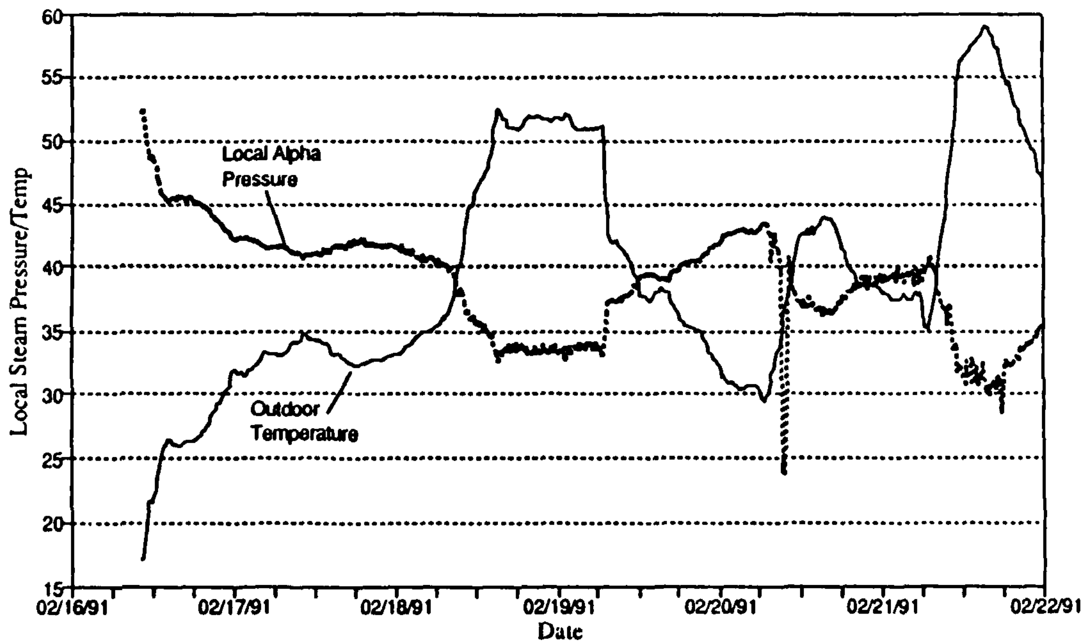


**Figure 10. Local Alpha Steam Pressure/Temperature Graph, February 16-22, 1991.**

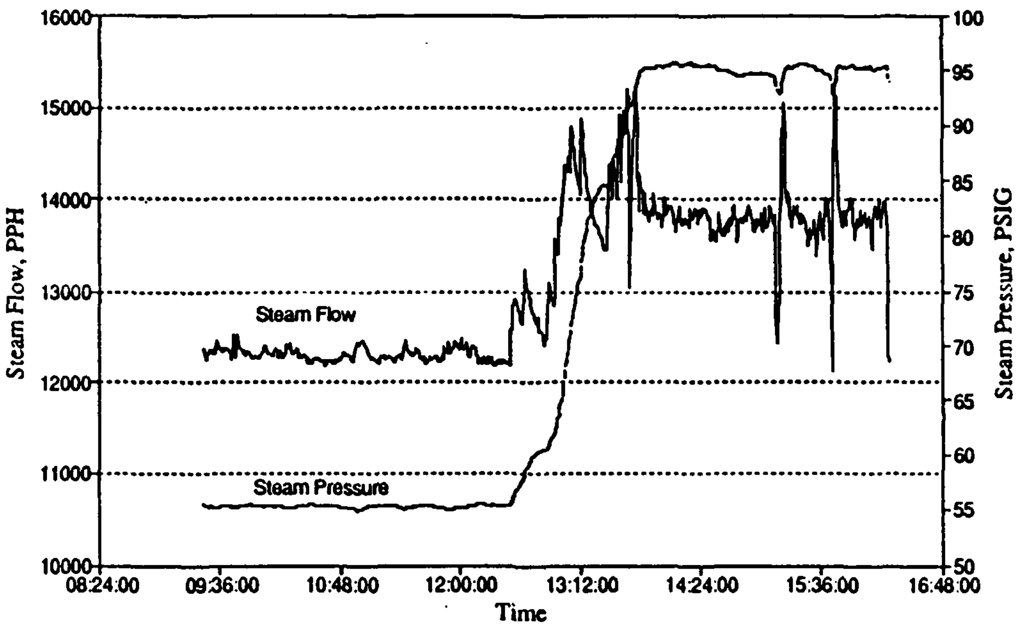


**Figure 11. Beta Steam Flow vs Steam Pressure, June 25, 1991.**

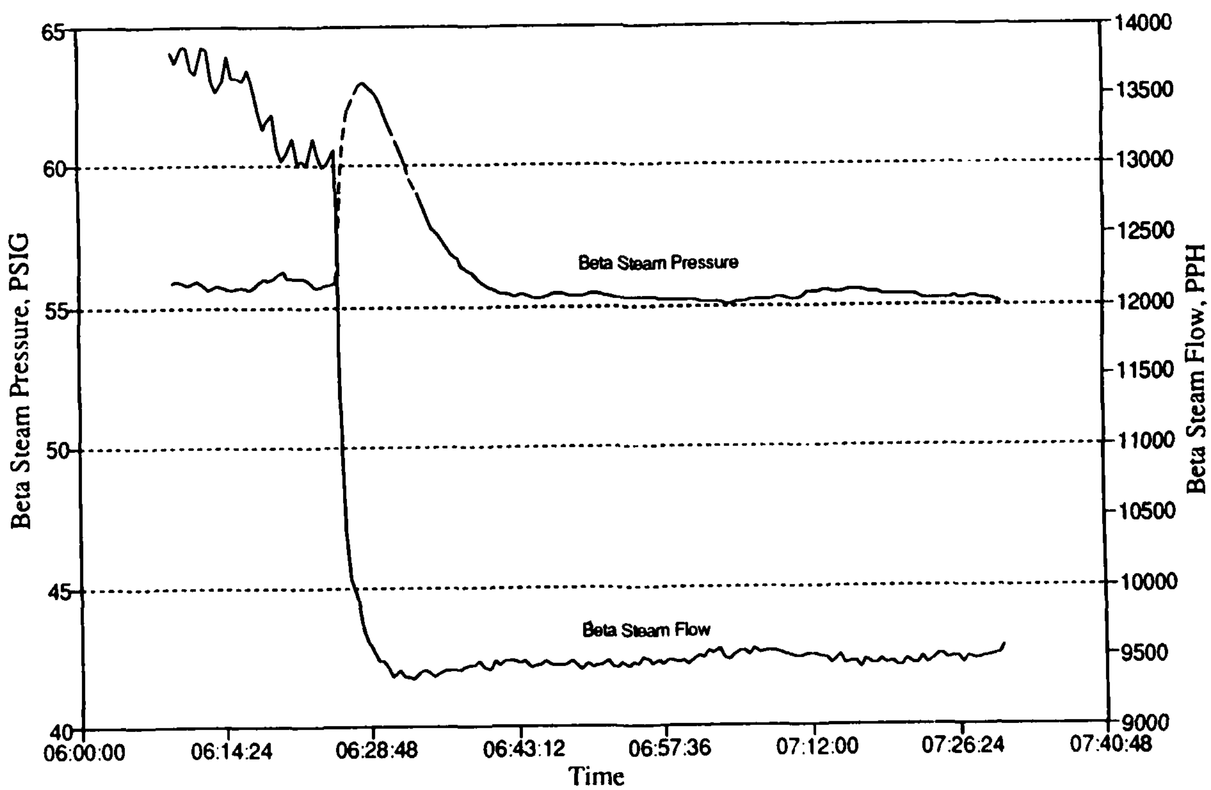


**Figure 12. Control System Response to Change in Beta Steam Flow, April 24, 1991.**

# 4 DATA COLLECTION

## Data Collection and Analysis Scheme

To evaluate controller operation and calculate savings, a simple data collection and analysis scheme was needed. Local and remote steam pressure, outside air temperature, and line steam flow readings were taken every 30 seconds. These values were averaged over 15 minutes and stored in weekly files. An Acurex Autograph 800 was used to gather and store the data. A sample of the data is shown below. See Appendix D for a more detailed description. The data are presented in the following format:

| | | local steam press. | | | | remote steam press. | | | steam flow | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| date, | time, | alpha, | beta, | delta, | temperature, | alpha, | beta, | delta, | alpha, | beta, | delta |
| 04/01/91, | 00:12:30, | 37.9, | 55.5, | 77.8, | 40.5, | 36.8, | 52.3, | 69.5, | 1836.6, | 15270.4, | 1869.9 |
| 04/01/91, | 00:27:30, | 37.8, | 55.0, | 77.6, | 40.8, | 36.6, | 52.1, | 69.6, | 1146.9, | 15637.3, | 1276.8 |
| 04/01/91, | 00:42:30, | 37.8, | 55.2, | 77.6, | 40.7, | 36.9, | 52.1, | 69.6, | 1556.6, | 15672.2, | 1302.7 |
| 04/01/91, | 00:57:30, | 37.9, | 55.6, | 77.8, | 40.6, | 36.7, | 52.5, | 69.9, | 1210.5, | 15458.5, | 1221.9 |

Data were transmitted from the sensors as 4-20 ma signals. All of the measurement signals were routed through a resistor on the terminal board to isolate the control loop from the data acquisition loop. See Appendix E for wiring diagrams and circuit drawings. The Acurex measured the signals and converted them into their respective engineering units of measure before storing them. The steam pressures and outside air temperature were used to evaluate the controller status. The line steam flows and total steam flow from monthly boiler log sheets supplied by Fort Harrison were used along with temperature data to determine the total savings generated by the system.

After the data were retrieved from the Autograph, they were converted into a database file. The data were averaged hourly and daily, and stored in monthly database files. Total daily steam flows were added to the daily averaged database file. These were retrieved from the monthly boiler plant log sheets. The daily averaged data were sorted by the local pressure into the following categories of files: (1) all three local pressures high (SDCS not functioning), (2) all three local pressures low (SDCS functioning), and (3) line pressures fluctuating (SDCS partially functional). The data sets for low and high pressure were then separated, and a regression analysis was carried out (see Appendix D).

## Boiler Logs

The total daily steam flow data were taken from the daily log files of the boiler plant. The steam flow, expressed in thousands of pounds of steam, was converted to an average hourly flow for each day (by dividing by 24 hours). These data were then added to the data collected from the Acurex. Daily steam flows were used to reduce possible errors caused by inaccuracies in the meter reading interval. For example, if an operator was 10 minutes late in taking an hourly steam flow reading, that reading would be high by 17 percent. In using the daily steam flows, the error from a 10 minute late reading would affect the overall daily steam flow reading by only 0.7 percent.

## ETAC Climate Data

Climate data for the Indianapolis Airport were obtained from ETAC. These data consisted of the mean maximum and minimum daily temperatures during the period of 1948 to 1989. The mean average daily temperature was calculated as the average of the maximum and minimum temperature for each particular day. A complete listing of the data is located in Appendix F.

## Data Filtering

*Summer vs Winter Loads*

Data were collected from the heating plant daily log files between November 1988 and August 1991. Data collected during boiler shutdowns and large distribution system repairs were considered invalid and were not incorporated into the study. The remaining data were sorted by season—summer and winter loads. Data were categorized under summer load when the line to the Series 600 buildings was shut off between mid-April and mid-November.

The data were considered baseline if the Beta and Delta local pressures were above 80 psi and the Alpha line pressure was above 50 psi. The low cutoff point for the local Alpha pressure was used to better balance the data sets. The effect of the Alpha steam pressure on the Alpha steam flow—and therefore, the total steam flow—was slight. This insensitivity to pressure was caused by the Alpha line's physical characteristics. This gave researchers much leeway in the location of the Alpha cutoff point. Each set of data was first sorted and separated using the local Beta pressure as the key. This procedure was repeated on the remaining data using the local Delta and Alpha pressure respectively (see Appendix D). These data were separated from the rest and least squares linear regressions were done on both the winter and summer load data.

*Steam Production Without SDCS*

Figure 13 shows the linear regression for the baseline winter steam load. The equation of the regression line is:

$$\text{Steam Flow } (10^3 \text{ lb/hr}) = 88.7 - 0.8565 \times T \qquad \text{[Eq 7]}$$

where $R^2 = 0.720$ (correlation coefficient)
$T$ = ambient temperature.

The average daily temperature ranged from 12 to 60 °F. An $R^2$ value of about 0.720 reflects a strong correlation between steam flow and temperature.

Figure 14 shows the linear regression for the summer baseline load. The baseline for the summer steam load showed a slight positive slope due to a cooling load generated by chillers in Building 400. The equation for the summer baseline regression line is:

$$\text{Steam Flow } (10^3 \text{ lb/hr}) = 3.93 + 0.319 \times T \qquad \text{[Eq 8]}$$

where $R^2 = 0.31$ (correlation coefficient)
$T$ = ambient temperature.

The average daily temperatures ranged from 63 to 85 °F. The correlation shows a weak dependence on temperature. This weak correlation may be due partially to maintenance and repair of parts of the distribution system and the small range of temperatures that occurred.

*Steam Production Using SDCS*

Winter steam flow data collected while SDCS was in use were separated in the same manner as the baseline data. Datum was considered valid if it was within 10 psi of the setpoint corresponding to the outdoor temperature. Figure 15 shows the relationship between steam flow and average winter daily outdoor temperature when SDCS was in use.

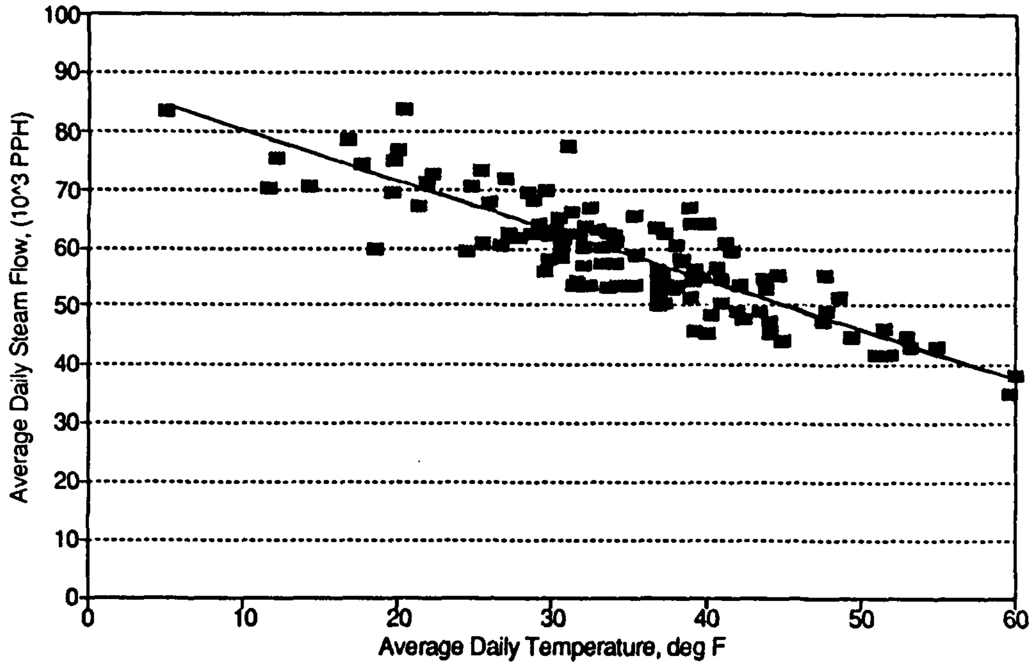


**Figure 13. Winter Baseline Steam Load.**

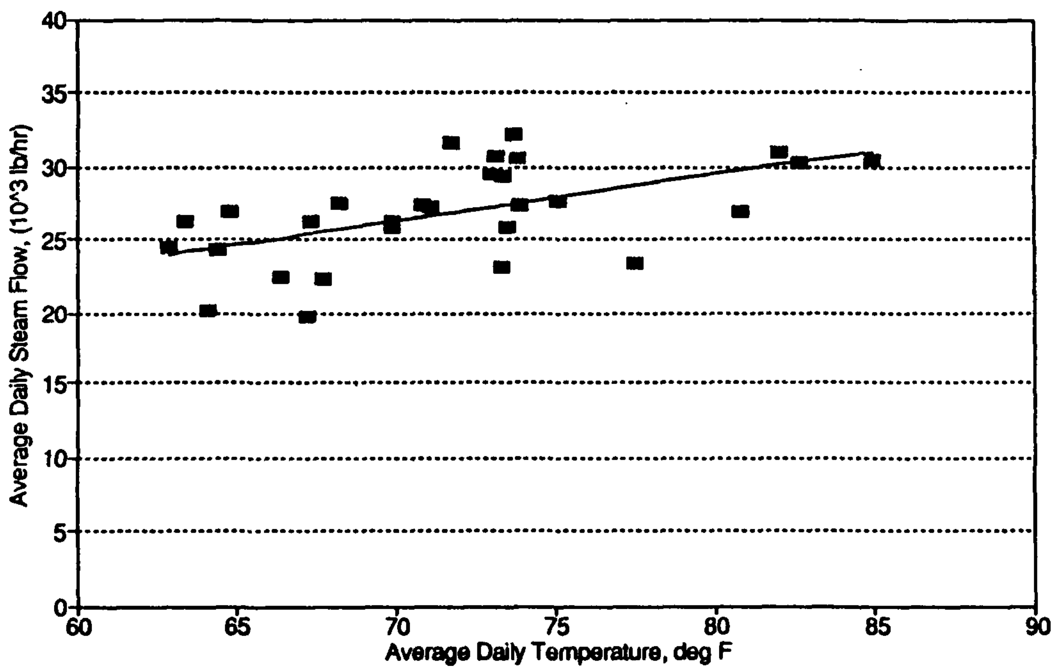


**Figure 14. Summer Baseline Steam Load.**

A multiple regression using the temperature and the square of the temperature was performed on the data. The resulting equation for the steam flow was:

$$\text{Steam Flow } (10^3 \text{ lb/hr}) = 91.9334 - (1.5073 \times T) + (0.00835 \times T^2) \qquad \text{[Eq 9]}$$

where $R^2 = 0.898$ (correlation coefficient)
T = ambient temperature.

The quadratic nature of the curve is appropriate due to the quadratic nature of the pressure setpoints. A strong correlation can be seen in this quadratic relation.

Figure 16 shows the linear regression for the summer steam load with SDCS, which, like the summer baseline load (Figure 14), also showed a slight positive slope due to the cooling load generated by chillers in Building 400. The equation for the summer load regression line is:

$$\text{Steam Flow } (10^3 \text{ lb/hr}) = 9.36 + 0.20 \times T \qquad \text{[Eq 10]}$$

where $R^2 = 0.163$ (correlation coefficient)
T = ambient temperature.

The average daily temperatures ranged from 63 to 85 °F. The correlation shows a weak dependence on temperature. Again, this weak correlation may be due partially to maintenance and repair of parts of the distribution system and the small range of temperatures that occurred. The summer load is linear in nature because the pressures are held constant at temperatures above 60 °F.

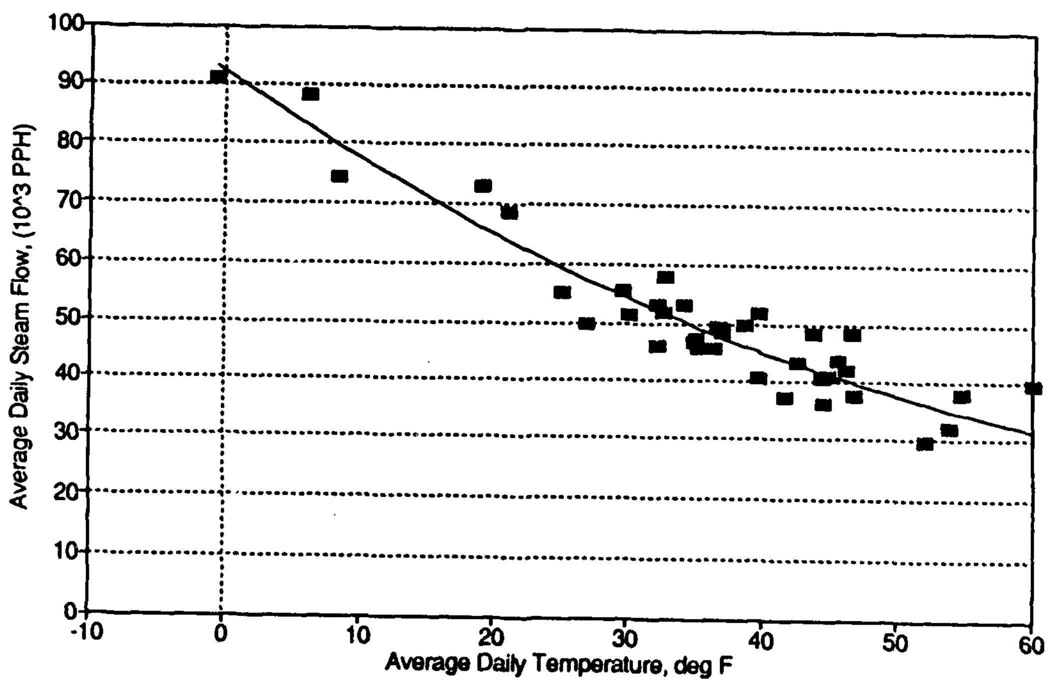


**Figure 15. Winter Steam Load with SDCS.**

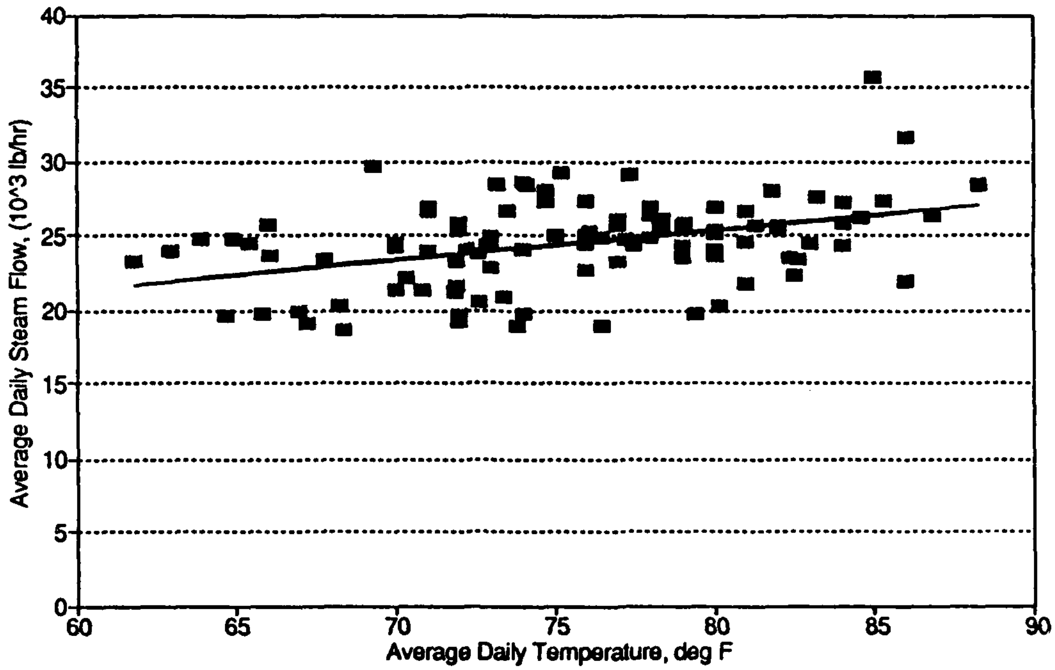


**Figure 16. Summer Steam Load with SDCS.**

## 5 RESULTS OF DATA ANALYSIS

### Calculation of Savings

An equation for energy savings was calculated by taking the difference of the regressions of the baseline and SDCS loads for both summer and winter. Figures 17 and 18 show the steam savings as related to average ambient temperature. The operating parameters specified in Chapter 3 (see "Operating Costs and Parameters") were used for all savings calculations. The load equations were calculated in terms of average daily steam flow. The average daily temperatures from the ETAC climate data (Appendix F) were used with the equations for energy savings to calculate the total summer, winter, and annual savings. When the average daily temperature was below 60 °F, an estimated fixed savings of 1,710 lb/hr was used for the summer load. This estimated value was used because there were not enough data below 60 °F to calculate the actual figure.

### Summary of Savings Using SDCS

Table 9 shows a summary of savings projected at Fort Harrison based on data from the demonstration of SDCS. The total steam savings were calculated using the methods described above. Values for fuel cost and boiler efficiency, as discussed in Chapter 3, were used to calculate the total gas savings and total dollar savings.

The actual steam and gas usage values were taken from the monthly boiler log summaries. These data were used to further verify the models. Differences between the actual values and model values are due to yearly temperature variations and to the use of SDCS during portions of 1990 and 1991.

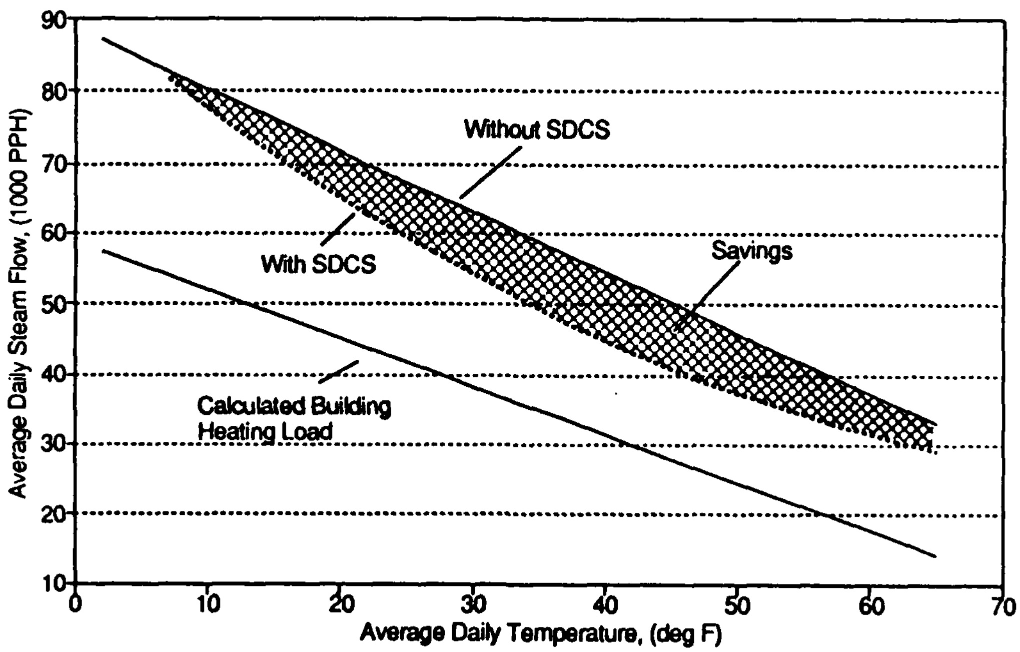


**Figure 17. Winter Steam Savings.**

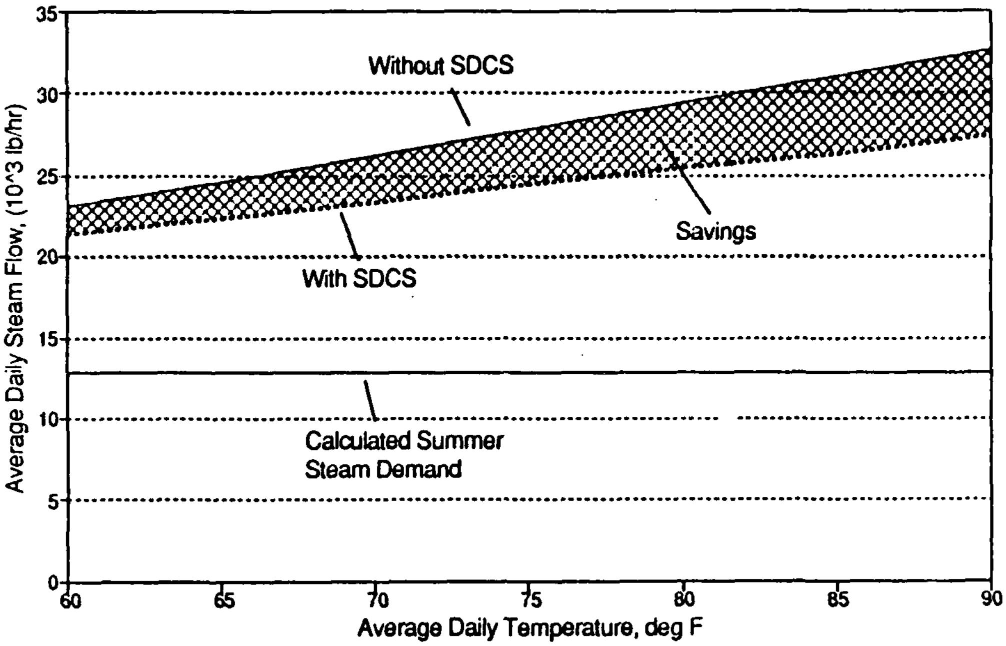


**Figure 18. Summer Steam Savings.**

**Table 9**

**Projected Savings Using SDCS**

| | Summer | Winter | Total |
|---|---|---|---|
| Total Days | 212 | 153 | 365 |
| Total Steam Produced ($10^3$ lb) | | | |
| Without SDCS | 129092 | 214529 | 343621 |
| With SDCS | 115983 | 182587 | 298570 |
| Actual (90-91 average)* | 130822 | 177591 | 308413 |
| Savings | 13109 | 31942 | 45051 |
| Total Gas Used (KSCF**) | | | |
| Without SDCS | 160783 | 267193 | 427976 |
| With SDCS | 144456 | 227410 | 371866 |
| Actual (90-91 average)* | 160467 | 211296 | 371763 |
| Savings | 16327 | 39783 | 56111 |
| Total Gas Used (MBtu) | | | |
| Without SDCS | 152743 | 253834 | 406577 |
| With SDCS | 137233 | 216040 | 353272 |
| Actual (90-91 average)* | 152444 | 200731 | 353175 |
| Savings | 15511 | 37794 | 53305 |
| Total Gas Usage ($) | | | |
| Without SDCS | 4[illegible]8402 | 828260 | 1326662 |
| With SDCS | 447790 | 704937 | 1152727 |
| Actual (90-91 average)* | 497424 | 654986 | 1152410 |
| Savings ($) | 50612 | 123323 | 173934 |

*Summer included the period of May through November, and winter consisted of the period from December through April. Averages were based on actual gas use of 376,523 KSCF for 1990 and 367,002 KSCF for 1991.
**KSCF: thousands of standard cubic feet.

**Statistical Validation of Results**

An external reference test was used to establish the validity of the data models (Box, Hunter, and Hunter 1978). Separate tests were done on the summer and winter loads. The baseline data were used as the reference. The winter loads were validated using $R^2$ values calculated from the data models. These $R^2$ values varied between 0.72 and 0.9, showing a strong correlation between the models and the actual data (when $R^2=1$, a perfect fit is indicated). Summer data $R^2$ values show a weak correlation (Equations 7, 8, 9, and 10). Factors contributing to the weak correlation may have included maintenance, a narrow outdoor temperature range during the summer test period, and general steam flow variability. Even with the weak correlation (0.16 to 0.31), however, the external reference test supported the savings estimates.

The null hypothesis was that if SDCS was not improving the efficiency of the steam distribution process, then average daily steam flow with SDCS operating would be distributed around the baseline data regression line. The linear regression of the baseline data was used as the mean reference line. The relevant reference set used was the average daily steam flow data taken while SDCS was operating. Determining factors for the separation of the data are explained in Chapter 3 under "Data Filtering."

Every data point in the relevant reference sets was compared to the mean reference lines for the winter and summer data. Only five of the 38 data points (13.2 percent) for the winter load were at or above the baseline regression. A frequency chart of the differences (Figure 19) was plotted to show the distribution of the data. The mean saving was 7,315 pph, and 76 percent of the data depict a savings of between 3,000 and 14,000 pph.

For the summer load, 18 of the 107 data points (16.8 percent) were at or above the baseline regression. A frequency chart of these data (Figure 20) was plotted to show its distribution. The mean saving was 3,360 pph, with 76 percent of the points showing a savings of between 1,000 and 7,500 pph.

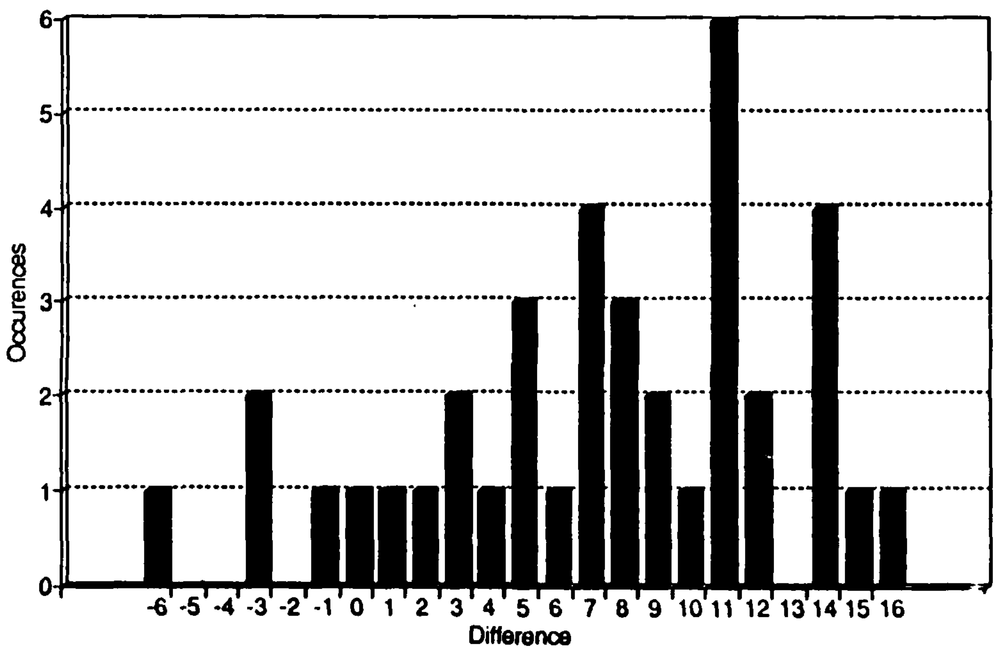


**Figure 19. Frequency Chart for Winter Steam Savings.**

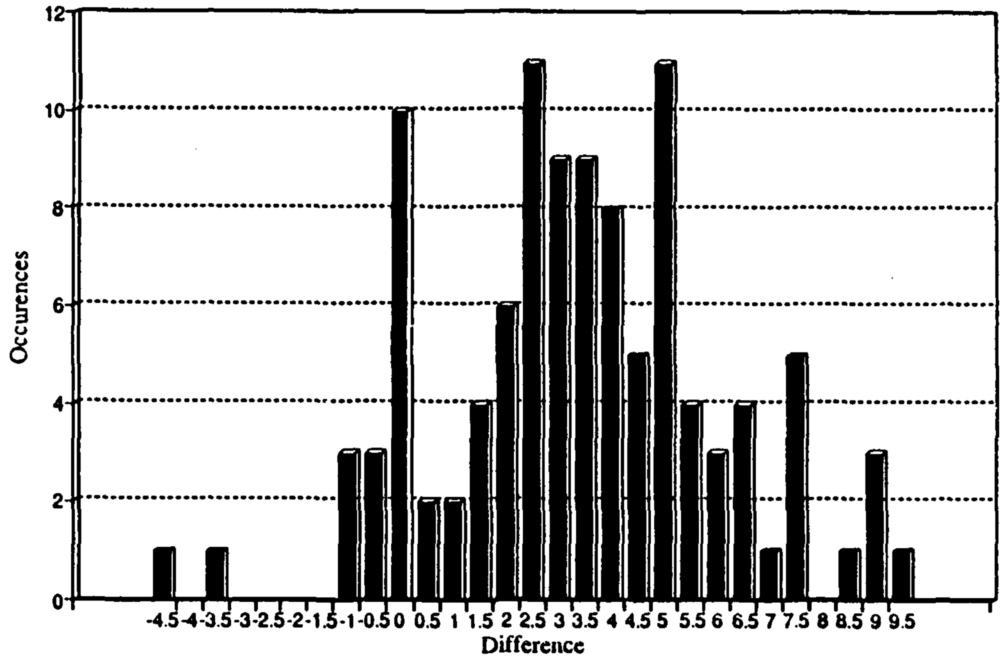


**Figure 20. Frequency Chart for Summer Steam Savings.**

# 6 CONCLUSIONS

## Payback

Researchers found that SDCS is a technically and economically viable improvement over current operating procedures. Analyses of the demonstration results show that the simple payback for SDCS is less than 1 year. Steam consumption data collected during the demonstration portion of this project at Fort Benjamin Harrison indicate that a savings of approximately 53,305 MBtu can be achieved (Table 9). The savings correspond to a reduction in the annual steam production of about 45 million pounds of steam. Using a 1990 fuel cost of $3.26 per MBtu and a boiler efficiency of 84 percent, total fuel savings equalled about $174,000. This savings represents a 13 percent reduction in annual cost. The capital cost of equipment and installation (during FY87) for the demonstration project was approximately $161,000 (Table 8).

The demonstration of SDCS at Fort Benjamin Harrison showed a significant potential for savings from reduced thermal and leak losses in central steam heat distribution systems. A properly designed SDCS is an economical and technical improvement over current operating control procedures. Distribution system type and layout, and end user requirements can influence the effectiveness of the system.

A comprehensive preliminary evaluation of an installation's central heating system is essential to a properly working SDCS. Developing an accurate model of the distribution system and steam usage should be the first step. Then economic feasibility can be determined through life-cycle costing procedures. Also, it must be confirmed that steam traps and PRV are correctly sized to work efficiently throughout the operating range of the SDCS.

**METRIC CONVERSION TABLE**

| | | |
|---|---|---|
| 1 in. | = | 25.4 mm |
| 1 ft | = | 0.305 m |
| 1 psi | = | 6.89 kPa |
| 1 lb | = | 0.453 kg |
| 1 cu ft | = | 0.028 $m^3$ |
| 1 mi | = | 1.61 km |
| 1 sq ft | = | 0.093 $m^2$ |
| 1 μm | = | $1 \times 10^{-6}$m |
| 1 gal | = | 3.78 l |
| °F | = | (°C + 17.78) x 1.8 |
| °C | = | 0.55(°F-32) |
| 1 yd | = | 0.9144 m |

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## APPENDIX A: SHDP Input and Output Files

Ft. Harrison - 100 PSI and 0 deg F

SYSTEM VARIABLES AND EXECUTION CONTROLS

FLOW TOLERANCE = 10.00 lbm/hr
UNKNOWN PARAMETER TOLERANCE = .000500
UNKNOWN PRESSURE TOLERANCE = .000050
UNKNOWN NODE FLOW TOLERANCE = 1.000 lbm/hr

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| PC = | 20 | 1 | 5 | 20 | 1 | 4 | 4 | 0 | 0 | 0 |
| UNS = | 1 | 2 | 2 | 2 | 4 | 3 | 1 | 1 | 2 | 2 |

PIPE DESCRIPTION SECTION

| NCE NUM | FROM NODE | TO NODE | STATUS | DIAMETER (in) | LENGTH (ft) | RELATIVE ROUGHNESS | HEAT LOSS COEF (Btu/hr-ft-F) | TEMP (F) |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | A1 | | 8.0 | 600.+ 0. | .313E-3 | 1.40 | 40.0 |
| 2 | A1 | 1 | | 8.0 | 500.+ 0. | .313E-3 | 1.40 | 40.0 |
| 3 | 2 | B1 | | 10.0 | 260.+ 0. | .250E-3 | 1.10 | 40.0 |
| 4 | B1 | B2 | | 10.0 | 540.+ 0. | .250E-3 | 1.10 | 40.0 |
| 5 | B2 | B2B | | 4.0 | 340.+ 0. | .620E-3 | .40 | 40.0 |
| 6 | B2B | 13 | | 2.1 | 110.+ 0. | .121E-2 | .20 | 40.0 |
| 7 | B2B | 17 | | 2.1 | 120.+ 0. | .121E-2 | .20 | 40.0 |
| 8 | B2 | 18 | | 2.1 | 150.+ 0. | .121E-2 | .20 | 40.0 |
| 9 | 18 | 26 | | 2.1 | 100.+ 0. | .121E-2 | .20 | 40.0 |
| 10 | 26 | 28 | | 2.1 | 100.+ 0. | .121E-2 | .20 | 40. |
| 11 | B2 | B2C | | 5.1 | 210.+ 0. | .495E-3 | .60 | 40. |
| 12 | B2C | 611 | | 2.1 | 170.+ 0. | .121E-2 | .20 | 40.0 |
| 13 | B2C | B2A | | 5.1 | 280.+ 0. | .495E-3 | .60 | 40.0 |
| 14 | B2A | 610 | | 2.1 | 300.+ 0. | .121E-2 | .20 | 40.0 |
| 15 | B2A | 613 | | 5.1 | 280.+ 0. | .495E-3 | .60 | 40.0 |
| 16 | 613 | 615 | | 4.0 | 180.+ 0. | .620E-3 | .40 | 40.0 |
| 17 | 613 | 614 | | 2.1 | 270.+ 0. | .495E-3 | .20 | 40.0 |
| 18 | 614 | 618 | | 3.1 | 320.+ 0. | .814E-3 | .90 | 40.0 |
| 19 | B2 | B3 | | 8.0 | 570.+ 0. | .313E-3 | .90 | 40.0 |
| 20 | B3 | B3A | | 4.0 | 1020.+ 0. | .620E-3 | .40 | 40.0 |
| 21 | B3A | 671 | | 3.1 | 690.+ 0. | .814E-3 | .90 | 40.0 |
| 22 | 671 | 672 | | 3.1 | 690.+ 0. | .814E-3 | .90 | 40.0 |
| 23 | B3A | 670 | | 4.0 | 40.+ 0. | .620E-3 | .40 | 40.0 |
| 24 | 670 | 669 | | 4.0 | 330.+ 0. | .620E-3 | .40 | 53.0 |
| 25 | 669 | 668 | | 4.0 | 250.+ 0. | .620E-3 | .40 | 40.0 |
| 26 | 668 | 667 | | 4.0 | 290.+ 0. | .620E-3 | .40 | 55.0 |
| 27 | 667 | B3B | | 4.0 | 250.+ 0. | .620E-3 | .40 | 57.0 |
| 28 | B3B | 622 | | 1.4 | 140.+ 0. | .181E-2 | .20 | 40.0 |
| 29 | B3B | 666 | | 4.0 | 50.+ 0. | .620E-3 | .40 | 40.0 |
| 30 | 666 | 665 | | 4.0 | 260.+ 0. | .620E-3 | .40 | 56.0 |
| 31 | 665 | B3C | | 4.0 | 120.+ 0. | .620E-3 | .40 | 52.0 |
| 32 | B3C | 624 | | 1.4 | 50.+ 0. | .181E-2 | .20 | 40.0 |
| 33 | 624 | 623 | | 1.4 | 70.+ 0. | .181E-2 | .20 | 40.0 |
| 34 | B3C | 664 | | 2.1 | 80.+ 0. | .121E-2 | .20 | 40.0 |
| 35 | 664 | 663 | | 2.1 | 180.+ 0. | .121E-2 | .20 | 40.0 |
| 36 | 663 | 662 | | 2.1 | 190.+ 0. | .121E-2 | .20 | 52.0 |
| 37 | B3 | B4 | | 8.0 | 420.+ 0. | .313E-3 | .90 | 40.0 |
| 38 | B4 | 604 | | 1.4 | 390.+ 0. | .181E-2 | .20 | 40.0 |
| 39 | B4 | B5 | | 8.0 | 430.+ 0. | .313E-3 | .90 | 40.0 |
| 40 | B5 | 600 | | 3.1 | 340.+ 0. | .814E-3 | .30 | 40.0 |
| 41 | B5 | B6 | | 8.0 | 680.+ 0. | .313E-3 | .90 | 40.0 |

PIPE DESCRIPTION SECTION

| NCE NUM | FROM NODE | TO NODE | STATUS | DIAMETER (in) | LENGTH (ft) | RELATIVE ROUGHNESS | HEAT LOSS COEF (Btu/hr-ft-F) | TEMP (F) |
|---|---|---|---|---|---|---|---|---|
| 42 | B6 | B6A | | 6.1 | 160.+ 0. | .412E-3 | .70 | 40.0 |
| 43 | B6A | 402 | | 3.1 | 120.+ 0. | .814E-3 | .30 | 40.0 |
| 44 | B6A | B7 | | 6.1 | 240.+ 0. | .412E-3 | .70 | 40.0 |
| 45 | B7 | 401 | | 3.1 | 120.+ 0. | .814E-3 | .30 | 40.0 |
| 46 | B7 | 400 | | 6.1 | 770.+ 0. | .412E-3 | .70 | 40.0 |
| 47 | B7 | C7 | | 6.1 | 330.+ 0. | .412E-3 | .50 | 40.0 |
| 48 | B6 | B8 | | 8.0 | 1270.+ 0. | .313E-3 | .90 | 40.0 |
| 49 | B8 | B8A | | 6.1 | 330.+ 0. | .412E-3 | .70 | 40.0 |
| 50 | B8A | 502 | | 2.1 | 440.+ 0. | .121E-2 | .20 | 40.0 |
| 51 | B8A | 500 | | 6.1 | 500.+ 0. | .412E-3 | .70 | 40.0 |
| 52 | B8 | B9 | | 6.1 | 520.+ 0. | .412E-3 | .70 | 40.0 |
| 53 | B9 | 538 | | 6.1 | 120.+ 0. | .412E-3 | .70 | 40.0 |
| 54 | 538 | 537 | | 6.1 | 130.+ 0. | .412E-3 | .70 | 40.0 |
| 55 | 537 | 539 | | 6.1 | 240.+ 0. | .412E-3 | .70 | 40.0 |
| 56 | 2 | D1 | | 11.9 | 70.+ 0. | .209E-3 | 1.30 | 40.0 |
| 57 | D1 | D1A | | 11.9 | 640.+ 0. | .209E-3 | 1.30 | 40.0 |
| 58 | D1A | C1 | | 10.0 | 90.+ 0. | .250E-3 | .70 | 40.0 |
| 59 | C1 | 19 | | 2.1 | 150.+ 0. | .121E-2 | .10 | 40.0 |
| 60 | C1 | 31 | | 10.0 | 800.+ 0. | .250E-3 | .70 | 40.0 |
| 61 | 31 | C3 | | 10.0 | 270.+ 0. | .250E-3 | .70 | 40.0 |
| 62 | C3 | 32 | | 4.0 | 200.+ 0. | .620E-3 | .30 | 40.0 |
| 63 | C3 | 35 | | 4.0 | 200.+ 0. | .620E-3 | .30 | 40.0 |
| 64 | C3 | C4 | | 8.0 | 520.+ 0. | .313E-3 | .50 | 40.0 |
| 65 | C4 | 427 | | 2.1 | 190.+ 0. | .121E-2 | .10 | 40.0 |
| 66 | C4 | C5 | | 8.0 | 300.+ 0. | .313E-3 | .50 | 40.0 |
| 67 | C5 | 410 | | 6.1 | 260.+ 0. | .412E-3 | .40 | 40.0 |
| 68 | 410 | C7 | | 6.1 | 220.+ 0. | .412E-3 | .40 | 40.0 |
| 69 | C7 | 421 | | 4.0 | 140.+ 0. | .620E-3 | .30 | 40.0 |
| 70 | 421 | 420 | | 3.1 | 190.+ 0. | .814E-3 | .20 | 40.0 |
| 71 | C5 | C8 | | 3.1 | 340.+ 0. | .814E-3 | .20 | 40.0 |
| 72 | C8 | 424 | | 2.1 | 90.+ 0. | .121E-2 | .20 | 40.0 |
| 73 | 424 | 423 | | 2.1 | 80.+ 0. | .121E-2 | .20 | 40.0 |
| 74 | 423 | 422 | | 2.1 | 70.+ 0. | .121E-2 | .20 | 40.0 |
| 75 | C8 | 425 | | 2.1 | 60.+ 0. | .121E-2 | .20 | 40.0 |
| 76 | 425 | 426 | | 2.1 | 170.+ 0. | .121E-2 | .20 | 40.0 |
| 77 | C8 | 428 | | 3.1 | 330.+ 0. | .814E-3 | .30 | 40.0 |
| 78 | 428 | C9 | | 3.1 | 120.+ 0. | .814E-3 | .30 | 40.0 |
| 79 | C9 | 429 | | 1.6 | 170.+ 0. | .155E-2 | .20 | 40.0 |
| 80 | C9 | C10 | | 3.1 | 210.+ 0. | .814E-3 | .30 | 40.0 |
| 81 | C10 | C11 | | 1.6 | 110.+ 0. | .155E-2 | .20 | 40.0 |
| 82 | C11 | 432 | | 1.6 | 90.+ 0. | .155E-2 | .20 | 40.0 |
| 83 | C11 | 430 | | 1.6 | 410.+ 0. | .155E-2 | .20 | 40.0 |
| 84 | C10 | 431 | | 1.6 | 350.+ 0. | .155E-2 | .20 | 40.0 |
| 85 | C10 | 434 | | 2.1 | 200.+ 0. | .121E-2 | .20 | 40.0 |
| 86 | 434 | 40 | | 2.1 | 590.+ 0. | .121E-2 | .20 | 40.0 |
| 87 | 40 | 39 | | 2.1 | 340.+ 0. | .121E-2 | .20 | 40.0 |
| 88 | D1A | D2 | | 10.0 | 580.+ 0. | .250E-3 | .70 | 40.0 |
| 89 | D2 | D3 | | 10.0 | 790.+ 0. | .250E-3 | .70 | 40.0 |
| 90 | D3 | 20 | | 3.1 | 330.+ 0. | .814E-3 | .20 | 40.0 |
| 91 | D3 | D4 | | 10.0 | 1190.+ 0. | .250E-3 | .70 | 40.0 |
| 92 | D4 | D5 | | 10.0 | 520.+ 0. | .250E-3 | .70 | 40.0 |
| 93 | D5 | 101 | | 3.1 | 130.+ 0. | .814E-3 | .20 | 40.0 |
| 94 | D5 | D6 | | 10.0 | 840.+ 0. | .250E-3 | .70 | 40.0 |
| 95 | D6 | 51 | | 3.1 | 330.+ 0. | .814E-3 | .20 | 40.0 |

PIPE DESCRIPTION SECTION

| NCE NUM | FROM NODE | TO NODE | STATUS | DIAMETER (in) | LENGTH (ft) | RELATIVE ROUGHNESS | HEAT LOSS COEF (Btu/hr-ft-F) | TEMP (F) |
|---|---|---|---|---|---|---|---|---|
| 96 | 51 | 472 | | 3.1 | 150.+ 0. | .814E-3 | .20 | 40.0 |
| 97 | D6 | D7 | | 10.0 | 950.+ 0. | .250E-3 | .70 | 40.0 |
| 98 | D7 | D7A | | 6.1 | 280.+ 0. | .412E-3 | .40 | 40.0 |
| 99 | D7A | 456 | | 5.1 | 50.+ 0. | .495E-3 | .40 | 40.0 |
| 100 | 456 | 455 | | 2.1 | 70.+ 0. | .121E-2 | .10 | 40.0 |
| 101 | D7A | 458 | | 5.1 | 50.+ 0. | .495E-3 | .40 | 40.0 |
| 102 | 458 | 457 | | 2.1 | 70.+ 0. | .121E-2 | .10 | 40.0 |
| 103 | D7A | D7B | | 6.1 | 570.+ 0. | .412E-3 | .40 | 40.0 |
| 104 | D7B | 444 | | 5.1 | 50.+ 0. | .495E-3 | .40 | 40.0 |
| 105 | 444 | 443 | | 2.1 | 70.+ 0. | .121E-2 | .10 | 40.0 |
| 106 | D7B | 446 | | 5.1 | 50.+ 0. | .495E-3 | .40 | 40.0 |
| 107 | 446 | 445 | | 2.1 | 70.+ 0. | .121E-2 | .10 | 40.0 |
| 108 | D7 | D8 | | 8.0 | 510.+ 0. | .313E-3 | .50 | 40.0 |
| 109 | D8 | D9 | | 8.0 | 1150.+ 0. | .313E-3 | .50 | 40.0 |
| 110 | D9 | 126 | | 8.0 | 530.+ 0. | .313E-3 | .50 | 40.0 |
| 111 | D9 | D10 | | 8.0 | 1230.+ 0. | .313E-3 | .50 | 40.0 |
| 112 | D10 | 300 | | 8.0 | 280.+ 0. | .313E-3 | .50 | 40.0 |

REGULATOR AND VALVE DESCRIPTION SECTION

| NCE NUM | FROM NODE | TO NODE | STATUS | SIZING COEFFICIENT | CONFIGURATION CONSTANT | MINIMUM PRESSURE DROP |
|---|---|---|---|---|---|---|
| 113 | 1 | 1A | UNKNOWN | 256.60 | 35.00 | .0 |
| 114 | 13 | 13A | UNKNOWN | 3.00 | 35.00 | .0 |
| 115 | 17 | 17A | UNKNOWN | 2.40 | 35.00 | .0 |
| 116 | 18 | 18A | UNKNOWN | 1.20 | 35.00 | .0 |
| 117 | 26 | 26A | UNKNOWN | 4.60 | 35.00 | .0 |
| 118 | 28 | 28A | UNKNOWN | 2.70 | 35.00 | .0 |
| 119 | 611 | 611A | UNKNOWN | 1.40 | 35.00 | .0 |
| 120 | 610 | 610A | UNKNOWN | 1.50 | 35.00 | .0 |
| 121 | 613 | 613A | UNKNOWN | 15.30 | 35.00 | .0 |
| 122 | 615 | 615A | UNKNOWN | 15.30 | 35.00 | .0 |
| 123 | 614 | 614A | UNKNOWN | 1.00 | 35.00 | .0 |
| 124 | 618 | 618A | UNKNOWN | 3.35 | 35.00 | .0 |
| 125 | 671 | 671A | UNKNOWN | 10.10 | 35.00 | .0 |
| 126 | 672 | 672A | UNKNOWN | 10.10 | 35.00 | .0 |
| 127 | 670 | 670A | UNKNOWN | 10.10 | 35.00 | .0 |
| 128 | 669 | 669A | UNKNOWN | 3.40 | 35.00 | .0 |
| 129 | 668 | 668A | UNKNOWN | 10.10 | 35.00 | .0 |
| 130 | 667 | 667A | UNKNOWN | 10.10 | 35.00 | .0 |
| 131 | 622 | 622A | UNKNOWN | .60 | 35.00 | .0 |
| 132 | 666 | 666A | UNKNOWN | 10.10 | 35.00 | .0 |
| 133 | 665 | 665A | UNKNOWN | 1.70 | 35.00 | .0 |
| 134 | 624 | 624A | UNKNOWN | .50 | 35.00 | .0 |
| 135 | 623 | 623A | UNKNOWN | .90 | 35.00 | .0 |
| 136 | 664 | 664A | UNKNOWN | 1.70 | 35.00 | .0 |
| 137 | 663 | 663A | UNKNOWN | 2.70 | 35.00 | .0 |
| 138 | 662 | 662A | UNKNOWN | 5.90 | 35.00 | .0 |
| 139 | 604 | 604A | UNKNOWN | 1.00 | 35.00 | .0 |
| 140 | 600 | 600A | UNKNOWN | 8.40 | 35.00 | .0 |
| 141 | 402 | 402A | UNKNOWN | 12.20 | 35.00 | .0 |
| 142 | 401 | 401A | UNKNOWN | 21.70 | 35.00 | .0 |
| 143 | 400 | 400A | UNKNOWN | 56.40 | 35.00 | .0 |
| 144 | 502 | 502A | UNKNOWN | 2.60 | 35.00 | .0 |
| 145 | 500 | 500A | UNKNOWN | 7.00 | 35.00 | .0 |
| 146 | 538 | 538A | UNKNOWN | 4.60 | 35.00 | .0 |
| 147 | 537 | 537A | UNKNOWN | 5.50 | 35.00 | .0 |
| 148 | 539 | 539A | UNKNOWN | 5.50 | 35.00 | .0 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 149 | 19 | 19A | UNKNOWN | 15.80 | 35.00 | .0 |
| 150 | 31 | 31A | UNKNOWN | 5.20 | 35.00 | .0 |
| 151 | 32 | 32A | UNKNOWN | 3.50 | 35.00 | .0 |
| 152 | 35 | 35A | UNKNOWN | .80 | 35.00 | .0 |
| 153 | 427 | 427A | UNKNOWN | 5.30 | 35.00 | .0 |
| 154 | 410 | 410A | UNKNOWN | 11.00 | 35.00 | .0 |
| 155 | 421 | 421A | UNKNOWN | 8.20 | 35.00 | .0 |
| 156 | 420 | 420A | UNKNOWN | 8.20 | 35.00 | .0 |
| 157 | 424 | 424A | UNKNOWN | 2.90 | 35.00 | .0 |
| 158 | 423 | 423A | UNKNOWN | .90 | 35.00 | .0 |
| 159 | 422 | 422A | UNKNOWN | 2.80 | 35.00 | .0 |
| 160 | 425 | 425A | UNKNOWN | 1.90 | 35.00 | .0 |
| 161 | 426 | 426A | UNKNOWN | 1.90 | 35.00 | .0 |
| 162 | 428 | 428A | UNKNOWN | 1.10 | 35.00 | .0 |
| 163 | 429 | 429A | UNKNOWN | 2.60 | 35.00 | .0 |
| 164 | 432 | 432A | UNKNOWN | 2.60 | 35.00 | .0 |
| 165 | 430 | 430A | UNKNOWN | 2.60 | 35.00 | .0 |
| 166 | 431 | 431A | UNKNOWN | 5.20 | 35.00 | .0 |
| 167 | 434 | 434A | UNKNOWN | 2.50 | 35.00 | .0 |
| 168 | 40 | 40A | UNKNOWN | 2.10 | 35.00 | .0 |
| 169 | 39 | 39A | UNKNOWN | 2.20 | 35.00 | .0 |
| 170 | 20 | 20A | UNKNOWN | 9.10 | 35.00 | .0 |
| 171 | 101 | 101A | UNKNOWN | 6.30 | 35.00 | .0 |
| 172 | 51 | 51A | UNKNOWN | 2.00 | 35.00 | .0 |
| 173 | 472 | 472A | UNKNOWN | 6.00 | 35.00 | .0 |
| 174 | 456 | 456A | UNKNOWN | 14.60 | 35.00 | .0 |
| 175 | 455 | 455A | UNKNOWN | 1.10 | 35.00 | .0 |
| 176 | 458 | 458A | UNKNOWN | 14.60 | 35.00 | .0 |
| 177 | 457 | 457A | UNKNOWN | 1.10 | 35.00 | .0 |
| 178 | 444 | 444A | UNKNOWN | 14.60 | 35.00 | .0 |
| 179 | 443 | 443A | UNKNOWN | 1.10 | 35.00 | .0 |
| 180 | 446 | 446A | UNKNOWN | 14.60 | 35.00 | .0 |
| 181 | 445 | 445A | UNKNOWN | 1.10 | 35.00 | .0 |
| 182 | 126 | 126A | UNKNOWN | 13.60 | 35.00 | .0 |
| 183 | 300 | 300A | UNKNOWN | 56.40 | 35.00 | .0 |

TRAP INPUT DATA

5.0 percent trap leakage

VAULT INPUT DATA

| VAULT NUMBER | NODE NAME | MAIN PIPE DIAMETER (in) | MAIN PIPE LENGTH (ft) | HEAT TRANSFER COEFFICIENT (Btu/hr-ft-F) | ENVIROMENT TEMPERATURE (F) |
|---|---|---|---|---|---|
| 1 | A1 | 7.98 | 10.00 | .70 | 50.0 |
| 2 | B1 | 10.02 | 10.00 | .90 | 50.0 |
| 3 | B2 | 10.02 | 10.00 | .90 | 50.0 |
| 4 | B2A | 5.05 | 10.00 | .60 | 50.0 |
| 5 | B2B | 4.03 | 10.00 | .40 | 50.0 |
| 6 | 614 | 5.05 | 10.00 | .60 | 50.0 |
| 7 | B3 | 7.98 | 10.00 | .70 | 50.0 |
| 8 | B3A | 4.03 | 5.00 | .30 | 50.0 |
| 9 | B3B | 4.03 | 5.00 | .30 | 50.0 |
| 10 | B3C | 4.03 | 5.00 | .30 | 50.0 |
| 11 | B4 | 7.98 | 10.00 | .70 | 50.0 |
| 12 | B5 | 7.98 | 10.00 | .70 | 50.0 |
| 13 | B6 | 7.98 | 10.00 | .70 | 50.0 |
| 14 | B6A | 6.07 | 10.00 | .60 | 50.0 |

| | | | | | |
|---|---|---|---|---|---|
| 15 | B7 | 6.07 | 10.00 | .60 | 50.0 |
| 16 | B8 | 7.98 | 10.00 | .70 | 50.0 |
| 17 | B8A | 6.07 | 10.00 | .60 | 50.0 |
| 18 | B9 | 6.07 | 10.00 | .60 | 50.0 |
| 19 | C1 | 10.02 | 10.00 | .90 | 50.0 |
| 20 | 31 | 10.02 | 10.00 | .90 | 50.0 |
| 21 | C3 | 7.98 | 10.00 | .70 | 50.0 |
| 22 | C4 | 6.07 | 10.00 | .70 | 50.0 |
| 23 | C5 | 7.98 | 10.00 | .70 | 50.0 |
| 24 | 410 | 6.07 | 10.00 | .70 | 50.0 |
| 25 | C7 | 7.98 | 10.00 | .70 | 50.0 |
| 26 | C8 | 3.07 | 10.00 | .30 | 50.0 |
| 27 | 428 | 3.07 | 10.00 | .30 | 50.0 |
| 28 | C9 | 3.07 | 10.00 | .30 | 50.0 |
| 29 | C10 | 3.07 | 10.00 | .30 | 50.0 |
| 30 | 434 | 2.07 | 10.00 | .20 | 50.0 |
| 31 | 40 | 2.07 | 10.00 | .20 | 50.0 |
| 32 | 39 | 2.07 | 10.00 | .20 | 50.0 |
| 33 | D1 | 11.94 | 10.00 | 1.30 | 50.0 |
| 34 | D2 | 10.02 | 10.00 | 1.10 | 50.0 |
| 35 | D3 | 10.02 | 10.00 | 1.10 | 50.0 |
| 36 | D4 | 10.02 | 10.00 | 1.10 | 50.0 |
| 37 | D5 | 10.02 | 10.00 | 1.10 | 50.0 |
| 38 | 51 | 3.07 | 10.00 | .30 | 50.0 |
| 39 | D6 | 10.02 | 10.00 | 1.10 | 50.0 |
| 40 | D7 | 10.02 | 10.00 | 1.10 | 50.0 |
| 41 | D7A | 6.07 | 10.00 | .70 | 50.0 |
| 42 | D7B | 6.07 | 10.00 | .70 | 50.0 |
| 43 | D8 | 7.98 | 10.00 | .90 | 50.0 |
| 44 | D9 | 7.98 | 10.00 | .90 | 50.0 |
| 45 | D10 | 7.98 | 10.00 | .90 | 50.0 |

NODE INPUT DATA

| NODE NAME | PRESSURE ( psig ) | NODE FLOW (lbm/hr) | NODE FLOW RETURNED | PIPE CONDS RETURNED | LOAD CONDS TEMPERATURE |
|---|---|---|---|---|---|
| 2 | 100.00 | 80000.? | .00 | .00 | 100.0 |
| A1 | 95.00? | 0. | .00 | .00 | 100.0 |
| 1 | 90.00? | 0. | .00 | .00 | 100.0 |
| 1A | 15.00 | -12820. | .60 | .00 | 100.0 |
| B1 | 95.00? | 0. | .00 | .00 | 100.0 |
| B2 | 95.00? | 0. | .00 | .00 | 100.0 |
| B2B | 95.00? | 0. | .00 | .00 | 100.0 |
| 13 | 95.00? | 0. | .00 | .00 | 100.0 |
| 13A | 15.00 | -314. | .60 | .00 | 100.0 |
| 17 | 95.00? | 0. | .00 | .00 | 100.0 |
| 17A | 15.00 | -253. | .60 | .00 | 100.0 |
| 18 | 95.00? | 0. | .00 | .00 | 100.0 |
| 18A | 15.00 | -124. | .60 | .00 | 100.0 |
| 26 | 95.00? | 0. | .00 | .00 | 100.0 |
| 26A | 15.00 | -476. | .60 | .00 | 100.0 |
| 28 | 95.00? | 0. | .00 | .00 | 100.0 |
| 28A | 15.00 | -283. | .60 | .00 | 100.0 |
| B2C | 95.00? | 0. | .00 | .00 | 100.0 |
| 611 | 95.00? | 0. | .00 | .00 | 100.0 |
| 611A | 15.00 | -151. | .60 | .00 | 100.0 |

| | | | | | |
|---|---|---|---|---|---|
| B2A | 95.00? | 0. | .00 | .00 | 100.0 |
| 610 | 95.00? | 0. | .00 | .00 | 100.0 |
| 610A | 15.00 | -158. | .60 | .00 | 100.0 |
| 613 | 95.00? | 0. | .00 | .00 | 100.0 |
| 613A | 15.00 | -1603. | .60 | .00 | 100.0 |
| 615 | 95.00? | 0. | .00 | .00 | 100.0 |
| 615A | 15.00 | -1603. | .60 | .00 | 100.0 |
| 614 | 90.00? | 0. | .00 | .00 | 100.0 |
| 614A | 15.00 | -109. | .60 | .00 | 100.0 |
| 618 | 90.00? | 0. | .00 | .00 | 100.0 |
| 618A | 15.00 | -352. | .60 | .00 | 100.0 |
| B3 | 95.00? | 0. | .00 | .00 | 100.0 |
| B3A | 95.00? | 0. | .00 | .00 | 100.0 |
| 671 | 90.00? | 0. | .00 | .00 | 100.0 |
| 671A | 15.00 | -1059. | .60 | .00 | 100.0 |
| 672 | 90.00? | 0. | .00 | .00 | 100.0 |
| 672A | 15.00 | -1059. | .60 | .00 | 100.0 |
| 670 | 90.00? | 0. | .00 | .00 | 100.0 |
| 670A | 15.00 | -1059. | .60 | .00 | 100.0 |
| 669 | 90.00? | 0. | .00 | .00 | 100.0 |
| 669A | 15.00 | -354. | .60 | .00 | 100.0 |
| 668 | 90.00? | 0. | .00 | .00 | 100.0 |
| 668A | 15.00 | -1059. | .60 | .00 | 100.0 |
| 667 | 90.00? | 0. | .00 | .00 | 100.0 |
| 667A | 15.00 | -1059. | .60 | .00 | 100.0 |
| B3B | 90.00? | 0. | .00 | .00 | 100.0 |
| 622 | 90.00? | 0. | .00 | .00 | 100.0 |
| 622A | 15.00 | -64. | .60 | .00 | 100.0 |
| 666 | 90.00? | 0. | .00 | .00 | 100.0 |
| 666A | 15.00 | -1059. | .60 | .00 | 100.0 |
| 665 | 90.00? | 0. | .00 | .00 | 100.0 |
| 665A | 15.00 | -173. | .60 | .00 | 100.0 |
| B3C | 90.00? | 0. | .00 | .00 | 100.0 |
| 624 | 90.00? | 0. | .00 | .00 | 100.0 |

NODE INPUT DATA

| NODE NAME | PRESSURE ( psig ) | NODE FLOW (lbm/hr) | NODE FLOW RETURNED | PIPE CONDS RETURNED | LOAD CONDS TEMPERATURE |
|---|---|---|---|---|---|
| 624A | 15.00 | -50. | .60 | .00 | 100.0 |
| 623 | 90.00? | 0. | .00 | .00 | 100.0 |
| 623A | 15.00 | -91. | .60 | .00 | 100.0 |
| 664 | 85.00? | 0. | .00 | .00 | 100.0 |
| 664A | 15.00 | -174. | .60 | .00 | 100.0 |
| 663 | 85.00? | 0. | .00 | .00 | 100.0 |
| 663A | 15.00 | -286. | .60 | .00 | 100.0 |
| 662 | 85.00? | 0. | .00 | .00 | 100.0 |
| 662A | 15.00 | -622. | .60 | .00 | 100.0 |
| B4 | 95.00? | 0. | .00 | .00 | 100.0 |
| 604 | 95.00? | 0. | .00 | .00 | 100.0 |
| 604A | 15.00 | -103. | .60 | .00 | 100.0 |
| B5 | 95.00? | 0. | .00 | .00 | 100.0 |
| 600 | 95.00? | 0. | .00 | .00 | 100.0 |
| 600A | 15.00 | -883. | .60 | .00 | 100.0 |
| B6 | 95.00? | 0. | .00 | .00 | 100.0 |
| B6A | 90.00? | 0. | .00 | .00 | 100.0 |
| 402 | 90.00? | 0. | .00 | .00 | 100.0 |
| 402A | 15.00 | -1279. | .60 | .00 | 100.0 |
| B7 | 90.00? | 0. | .00 | .00 | 100.0 |

| | | | | | |
|---|---|---|---|---|---|
| 401 | 90.00? | 0. | .00 | .00 | 100.0 |
| 401A | 15.00 | -2278. | .60 | .00 | 100.0 |
| 400 | 85.00? | 0. | .00 | .00 | 100.0 |
| 400A | 15.00 | -5908. | .60 | .00 | 100.0 |
| B8 | 95.00? | 0. | .00 | .00 | 100.0 |
| B8A | 90.00? | 0. | .00 | .00 | 100.0 |
| 502 | 90.00? | 0. | .00 | .00 | 100.0 |
| 502A | 15.00 | -274. | .60 | .00 | 100.0 |
| 500 | 90.00? | 0. | .00 | .00 | 100.0 |
| 500A | 15.00 | -724. | .60 | .00 | 100.0 |
| B9 | 90.00? | 0. | .00 | .00 | 180.0 |
| 538 | 90.00? | 0. | .00 | .00 | 100.0 |
| 538A | 15.00 | -483. | .60 | .00 | 100.0 |
| 537 | 90.00? | 0. | .00 | .00 | 100.0 |
| 537A | 15.00 | -582. | .60 | .00 | 100.0 |
| 539 | 90.00? | 0. | .00 | .00 | 100.0 |
| 539A | 15.00 | -582. | .60 | .00 | 100.0 |
| D1 | 100.00? | 0. | .00 | .00 | 100.0 |
| D1A | 100.00? | 0. | .00 | .00 | 100.0 |
| C1 | 95.00? | 0. | .00 | .00 | 100.0 |
| 19 | 95.00? | 0. | .00 | .00 | 100.0 |
| 19A | 15.00 | -1640. | .60 | .00 | 100.0 |
| 31 | 95.00? | 0. | .00 | .00 | 100.0 |
| 31A | 15.00 | -544. | .60 | .00 | 100.0 |
| C3 | 95.00? | 0. | .00 | .00 | 100.0 |
| 32 | 95.00? | 0. | .00 | .00 | 100.0 |
| 32A | 15.00 | -369. | .60 | .00 | 100.0 |
| 35 | 95.00? | 0. | .00 | .00 | 100.0 |
| 35A | 15.00 | -84. | .60 | .00 | 100.0 |
| C4 | 95.00? | 0. | .00 | .00 | 100.0 |
| 427 | 95.00? | 0. | .00 | .00 | 100.0 |
| 427A | 15.00 | -551. | .60 | .00 | 100.0 |
| C5 | 95.00? | 0. | .00 | .00 | 100.0 |
| 410 | 95.00? | 0. | .00 | .00 | 100.0 |

NODE INPUT DATA

| NODE NAME | PRESSURE ( psig ) | NODE FLOW (lbm/hr) | NODE FLOW RETURNED | PIPE CONDS RETURNED | LOAD CONDS TEMPERATURE |
|---|---|---|---|---|---|
| 410A | 15.00 | -1147. | .60 | .00 | 100.0 |
| C7 | 90.00? | 0. | .00 | .00 | 100.0 |
| 421 | 90.00? | 0. | .00 | .00 | 100.0 |
| 421A | 15.00 | -859. | .60 | .00 | 100.0 |
| 420 | 90.00? | 0. | .00 | .00 | 100.0 |
| 420A | 15.00 | -859. | .60 | .00 | 100.0 |
| C8 | 90.00? | 0. | .00 | .00 | 100.0 |
| 424 | 90.00? | 0. | .00 | .00 | 100.0 |
| 424A | 15.00 | -302. | .60 | .00 | 100.0 |
| 423 | 90.00? | 0. | .00 | .00 | 100.0 |
| 423A | 15.00 | -98. | .60 | .00 | 100.0 |
| 422 | 90.00? | 0. | .00 | .00 | 100.0 |
| 422A | 15.00 | -291. | .60 | .00 | 100.0 |
| 425 | 90.00? | 0. | .00 | .00 | 100.0 |
| 425A | 15.00 | -194. | .60 | .00 | 100.0 |
| 426 | 90.00? | 0. | .00 | .00 | 100.0 |
| 426A | 15.00 | -194. | .60 | .00 | 100.0 |
| 428 | 90.00? | 0. | .00 | .00 | 100.0 |
| 428A | 15.00 | -111. | .60 | .00 | 100.0 |
| C9 | 90.00? | 0. | .00 | .00 | 100.0 |

| | | | | | |
|---|---|---|---|---|---|
| C10 | 90.00? | 0. | .00 | .00 | 100.0 |
| C11 | 90.00? | 0. | .00 | .00 | 100.0 |
| 429 | 85.00? | 0. | .00 | .00 | 100.0 |
| 429A | 15.00 | -274. | .60 | .00 | 100.0 |
| 432 | 85.00? | 0. | .00 | .00 | 100.0 |
| 432A | 15.00 | -274. | .60 | .00 | 100.0 |
| 430 | 85.00? | 0. | .00 | .00 | 100.0 |
| 430A | 15.00 | -274. | .60 | .00 | 100.0 |
| 431 | 80.00? | 0. | .00 | .00 | 100.0 |
| 431A | 15.00 | -545. | .60 | .00 | 100.0 |
| 434 | 85.00? | 0. | .00 | .00 | 100.0 |
| 434A | 15.00 | -261. | .60 | .00 | 100.0 |
| 40 | 80.00? | 0. | .00 | .00 | 100.0 |
| 40A | 15.00 | -219. | .60 | .00 | 100.0 |
| 39 | 80.00? | 0. | .00 | .00 | 100.0 |
| 39A | 15.00 | -231. | .60 | .00 | 100.0 |
| D2 | 95.00? | 0. | .00 | .00 | 100.0 |
| D3 | 95.00? | 0. | .00 | .00 | 100.0 |
| 20 | 95.00? | 0. | .00 | .00 | 100.0 |
| 20A | 15.00 | -943. | .60 | .00 | 100.0 |
| D4 | 95.00? | 0. | .00 | .00 | 100.0 |
| D5 | 95.00? | 0. | .00 | .00 | 100.0 |
| 101 | 95.00? | 0. | .00 | .00 | 100.0 |
| 101A | 15.00 | -656. | .60 | .00 | 100.0 |
| D6 | 95.00? | 0. | .00 | .00 | 100.0 |
| 51 | 95.00? | 0. | .00 | .00 | 100.0 |
| 51A | 15.00 | -214. | .60 | .00 | 100.0 |
| 472 | 90.00? | 0. | .00 | .00 | 100.0 |
| 472A | 15.00 | -628. | .60 | .00 | 100.0 |
| D7 | 95.00? | 0. | .00 | .00 | 100.0 |
| D7A | 95.00? | 0. | .00 | .00 | 100.0 |
| 456 | 95.00? | 0. | .00 | .00 | 100.0 |
| 456A | 15.00 | -1528. | .60 | .00 | 100.0 |
| 455 | 95.00? | 0. | .00 | .00 | 100.0 |

NODE INPUT DATA

| NODE NAME | PRESSURE ( psig ) | NOL. FLOW (lbm/hr) | NODE FLOW RETURNED | PIPE CONDS RETURNED | LOAD CONDS TEMPERATURE |
|---|---|---|---|---|---|
| 455A | 15.00 | -119. | .60 | .00 | 100.0 |
| 458 | 95.00? | 0. | .00 | .00 | 100.0 |
| 458A | 15.00 | -1528. | .60 | .00 | 100.0 |
| 457 | 95.00? | 0. | .00 | .00 | 100.0 |
| 457A | 15.00 | -119. | .60 | .00 | 100.0 |
| D7B | 95.00? | 0. | .00 | .00 | 100.0 |
| 444 | 95.00? | 0. | .00 | .00 | 100.0 |
| 444A | 15.00 | -1528. | .60 | .00 | 100.0 |
| 443 | 95.00? | 0. | .00 | .00 | 100.0 |
| 443A | 15.00 | -119. | .60 | .00 | 100.0 |
| 446 | 95.00? | 0. | .00 | .00 | 100.0 |
| 446A | 15.00 | -1528. | .60 | .00 | 100.0 |
| 445 | 95.00? | 0. | .00 | .00 | 100.0 |
| 445A | 15.00 | -119. | .60 | .00 | 100.0 |
| D8 | 95.00? | 0. | .00 | .00 | 100.0 |
| D9 | 95.00? | 0. | .00 | .00 | 100.0 |
| 126 | 90.00? | 0. | .00 | .00 | 100.0 |
| 126A | 15.00 | -1426. | .60 | .00 | 100.0 |
| D10 | 90.00? | 0. | .00 | .00 | 100.0 |
| 300 | 90.00? | 0. | .00 | .00 | 100.0 |

| | | | | | |
|---|---|---|---|---|---|
| 300A | 15.00 | -4340. | .60 | .00 | 100.0 |

NODE CORRESPONDENCE TABLE AND LIST OF ADJACENT NODES

| NODE NUMBER | NODE NAME | ADJACENT NODES(BY NAME) | | | | |
|---|---|---|---|---|---|---|
| 1 | 2 | A1 | B1 | D1 | | |
| 2 | A1 | 1 | 2 | | | |
| 3 | 1 | 1A | A1 | | | |
| 4 | 1A | 1 | | | | |
| 5 | B1 | B2 | 2 | | | |
| 6 | B2 | B2B | 18 | B2C | B3 | B1 |
| 7 | B2B | 13 | 17 | B2 | | |
| 8 | 13 | 13A | B2B | | | |
| 9 | 13A | 13 | | | | |
| 10 | 17 | 17A | B2B | | | |
| 11 | 17A | 17 | | | | |
| 12 | 18 | 26 | 18A | B2 | | |
| 13 | 18A | 18 | | | | |
| 14 | 26 | 28 | 26A | 18 | | |
| 15 | 26A | 26 | | | | |
| 16 | 28 | 28A | 26 | | | |
| 17 | 28A | 28 | | | | |
| 18 | B2C | 611 | B2A | B2 | | |
| 19 | 611 | 611A | B2C | | | |
| 20 | 611A | 611 | | | | |
| 21 | B2A | 610 | 613 | B2C | | |
| 22 | 610 | 610A | B2A | | | |
| 23 | 610A | 610 | | | | |
| 24 | 613 | 615 | 614 | 613A | B2A | |
| 25 | 613A | 613 | | | | |

NODE CORRESPONDENCE TABLE AND LIST OF ADJACENT NODES

| NODE NUMBER | NODE NAME | ADJACENT NODES(BY NAME) | | |
|---|---|---|---|---|
| 26 | 615 | 615A | 613 | |
| 27 | 615A | 615 | | |
| 28 | 614 | 618 | 614A | 613 |
| 29 | 614A | 614 | | |
| 30 | 618 | 618A | 614 | |
| 31 | 618A | 618 | | |
| 32 | B3 | B3A | B4 | B2 |
| 33 | B3A | 671 | 670 | B3 |
| 34 | 671 | 672 | 671A | B3A |
| 35 | 671A | 671 | | |
| 36 | 672 | 672A | 671 | |
| 37 | 672A | 672 | | |
| 38 | 670 | 669 | 670A | B3A |
| 39 | 670A | 670 | | |
| 40 | 669 | 668 | 669A | 670 |
| 41 | 669A | 669 | | |
| 42 | 668 | 667 | 668A | 669 |
| 43 | 668A | 668 | | |
| 44 | 667 | B3B | 667A | 668 |
| 45 | 667A | 667 | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 46 | B3B | 622 | 666 | 667 | | |
| 47 | 622 | 622A | B3B | | | |
| 48 | 622A | 622 | | | | |
| 49 | 666 | 665 | 666A | B3B | | |
| 50 | 666A | 666 | | | | |
| 51 | 665 | B3C | 665A | 666 | | |
| 52 | 665A | 665 | | | | |
| 53 | B3C | 624 | 664 | 665 | | |
| 54 | 624 | 623 | 624A | B3C | | |
| 55 | 624A | 624 | | | | |
| 56 | 623 | 623A | 624 | | | |
| 57 | 623A | 623 | | | | |
| 58 | 664 | 663 | 664A | B3C | | |
| 59 | 664A | 664 | | | | |
| 60 | 663 | 662 | 663A | 664 | | |
| 61 | 663A | 663 | | | | |
| 62 | 662 | 662A | 663 | | | |
| 63 | 662A | 662 | | | | |
| 64 | B4 | 604 | B5 | B3 | | |
| 65 | 604 | 604A | B4 | | | |
| 66 | 604A | 604 | | | | |
| 67 | B5 | 600 | B6 | B4 | | |
| 68 | 600 | 600A | B5 | | | |
| 69 | 600A | 600 | | | | |
| 70 | B6 | B6A | B8 | B5 | | |
| 71 | B6A | 402 | B7 | B6 | | |
| 72 | 402 | 402A | B6A | | | |
| 73 | 402A | 402 | | | | |
| 74 | B7 | 401 | 400 | C7 | B6A | |
| 75 | 401 | 401A | B7 | | | |
| 76 | 401A | 401 | | | | |
| 77 | 400 | 400A | B7 | | | |
| 78 | 400A | 400 | | | | |
| 79 | B8 | B8A | B9 | B6 | | |

NODE CORRESPONDENCE TABLE AND LIST OF ADJACENT NODES

| NODE NUMBER | NODE NAME | ADJACENT NODES(BY NAME) | | | |
|---|---|---|---|---|---|
| 80 | B8A | 502 | 500 | B8 | |
| 81 | 502 | 502A | B8A | | |
| 82 | 502A | 502 | | | |
| 83 | 500 | 500A | B8A | | |
| 84 | 500A | 500 | | | |
| 85 | B9 | 538 | B8 | | |
| 86 | 538 | 537 | 538A | B9 | |
| 87 | 538A | 538 | | | |
| 88 | 537 | 539 | 537A | 538 | |
| 89 | 537A | 537 | | | |
| 90 | 539 | 539A | 537 | | |
| 91 | 539A | 539 | | | |
| 92 | D1 | D1A | 2 | | |
| 93 | D1A | C1 | D2 | D1 | |
| 94 | C1 | 19 | 31 | D1A | |
| 95 | 19 | 19A | C1 | | |
| 96 | 19A | 19 | | | |
| 97 | 31 | C3 | 31A | C1 | |
| 98 | 31A | 31 | | | |
| 99 | C3 | 32 | 35 | C4 | 31 |

| | | | | | |
|---|---|---|---|---|---|
| 100 | 32 | 32A | C3 | | |
| 101 | 32A | 32 | | | |
| 102 | 35 | 35A | C3 | | |
| 103 | 35A | 35 | | | |
| 104 | C4 | 427 | C5 | C3 | |
| 105 | 427 | 427A | C4 | | |
| 106 | 427A | 427 | | | |
| 107 | C5 | 410 | C8 | C4 | |
| 108 | 410 | C7 | 410A | C5 | |
| 109 | 410A | 410 | | | |
| 110 | C7 | 421 | B7 | 410 | |
| 111 | 421 | 420 | 421A | C7 | |
| 112 | 421A | 421 | | | |
| 113 | 420 | 420A | 421 | | |
| 114 | 420A | 420 | | | |
| 115 | C8 | 424 | 425 | 428 | C5 |
| 116 | 424 | 423 | 424A | C8 | |
| 117 | 424A | 424 | | | |
| 118 | 423 | 422 | 423A | 424 | |
| 119 | 423A | 423 | | | |
| 120 | 422 | 422A | 423 | | |
| 121 | 422A | 422 | | | |
| 122 | 425 | 426 | 425A | C8 | |
| 123 | 425A | 425 | | | |
| 124 | 426 | 426A | 425 | | |
| 125 | 426A | 426 | | | |
| 126 | 428 | C9 | 428A | C8 | |
| 127 | 428A | 428 | | | |
| 128 | C9 | 429 | C10 | 428 | |
| 129 | C10 | C11 | 431 | 434 | C9 |
| 130 | C11 | 432 | 430 | C10 | |
| 131 | 429 | 429A | C9 | | |
| 132 | 429A | 429 | | | |
| 133 | 432 | 432A | C11 | | |

NODE CORRESPONDENCE TABLE AND LIST OF ADJACENT NODES

| NODE NUMBER | NODE NAME | ADJACENT NODES(BY NAME) | | | |
|---|---|---|---|---|---|
| 134 | 432A | 432 | | | |
| 135 | 430 | 430A | C11 | | |
| 136 | 430A | 430 | | | |
| 137 | 431 | 431A | C10 | | |
| 138 | 431A | 431 | | | |
| 139 | 434 | 40 | 434A | C10 | |
| 140 | 434A | 434 | | | |
| 141 | 40 | 39 | 40A | 434 | |
| 142 | 40A | 40 | | | |
| 143 | 39 | 39A | 40 | | |
| 144 | 39A | 39 | | | |
| 145 | D2 | D3 | D1A | | |
| 146 | D3 | 20 | D4 | D2 | |
| 147 | 20 | 20A | D3 | | |
| 148 | 20A | 20 | | | |
| 149 | D4 | D5 | D3 | | |
| 150 | D5 | 101 | D6 | D4 | |
| 151 | 101 | 101A | D5 | | |
| 152 | 101A | 101 | | | |
| 153 | D6 | 51 | D7 | D5 | |

| | | | | | |
|---|---|---|---|---|---|
| 154 | 51 | 472 | 51A | D6 | |
| 155 | 51A | 51 | | | |
| 156 | 472 | 472A | 51 | | |
| 157 | 472A | 472 | | | |
| 158 | D7 | D7A | D8 | D6 | |
| 159 | D7A | 456 | 458 | D7B | D7 |
| 160 | 456 | 455 | 456A | D7A | |
| 161 | 456A | 456 | | | |
| 162 | 455 | 455A | 456 | | |
| 163 | 455A | 455 | | | |
| 164 | 458 | 457 | 458A | D7A | |
| 165 | 458A | 458 | | | |
| 166 | 457 | 457A | 458 | | |
| 167 | 457A | 457 | | | |
| 168 | D7B | 444 | 446 | D7A | |
| 169 | 444 | 443 | 444A | D7B | |
| 170 | 444A | 444 | | | |
| 171 | 443 | 443A | 444 | | |
| 172 | 443A | 443 | | | |
| 173 | 446 | 445 | 446A | D7B | |
| 174 | 446A | 446 | | | |
| 175 | 445 | 445A | 446 | | |
| 176 | 445A | 445 | | | |
| 177 | D8 | D9 | D7 | | |
| 178 | D9 | 126 | D10 | D8 | |
| 179 | 126 | 126A | D9 | | |
| 180 | 126A | 126 | | | |
| 181 | D10 | 300 | D9 | | |
| 182 | 300 | 300A | D10 | | |
| 183 | 300A | 300 | | | |

***** PROBLEM SUMMARY *****

183 NODES IN THE SYSTEM
112 PIPES IN THE SYSTEM
71 VALVES OR REGULATORS
5 PERCENT TRAP LEAKAGE
45 VAULTS IN THE SYSTEM
71 UNKNOWN PARAMETERS
111 UNKNOWN PRESSURES
1 UNKNOWN FLOWS

Ft. Harrison - 100 PSI and 0 deg F

SOLUTION COMPLETED IN 9 ITERATIONS
SOME NODES MAY NOT BE BALANCED

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 *** PROBLEM SUMMARY ***
183 NODES IN THE SYSTEM
112 PIPES IN THE SYSTEM
 71 VALVES OR REGULATORS
  5 PERCENT TRAP LEAKAGE
 45 VAULTS IN THE SYSTEM
 71 UNKNOWN PARAMETERS
111 UNKNOWN PRESSURES
  1 UNKNOWN FLOWS
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COMPUTED NODE DATA

| NODE NAME | PRESSURE ( psig ) | NODE FLOW (lbm/hr) | CONDS FLOW (lbm/hr) | FLOW LOSS (Btu/hr ) | CONDS LOSS (Btu/hr ) | TEMP (F) | RESIDUAL (lbm/hr) |
|---|---|---|---|---|---|---|---|
| 2 | 100.00 | 71445.8? | -204.0 | .0 | 63045.4 | 337.9 | -.34 |
| A1 | 99.30? | .0 | -258.6 | .0 | 79773.8 | 337.4 | -.09 |
| 1 | 98.74? | .0 | -117.4 | .0 | 36186.4 | 337.1 | .53 |
| 1A | 15.00 | -12819.8 | .0 | 337409.8 | .0 | 249.7 | .00 |
| B1 | 99.68? | .0 | -146.6 | .0 | 45261.3 | 337.7 | .96 |
| B2 | 99.02? | .0 | -232.3 | .0 | 71619.1 | 337.2 | -4.84 |
| B2B | 98.98? | .0 | -30.7 | .0 | 9460.9 | 337.2 | 9.74 |
| 13 | 98.88? | .0 | -3.7 | .0 | 1142.6 | 337.1 | -2.16 |
| 13A | 15.00 | -313.9 | .0 | 8261.7 | .0 | 249.7 | .00 |
| 17 | 98.90? | .0 | -4.0 | .0 | 1247.0 | 337.2 | -1.43 |
| 17A | 15.00 | -252.9 | .0 | 6656.2 | .0 | 249.7 | .00 |
| 18 | 98.01? | .0 | -8.3 | .0 | 2553.6 | 336.6 | -.02 |
| 18A | 15.00 | -124.1 | .0 | 3266.2 | .0 | 249.7 | .00 |
| 26 | 97.51? | .0 | -6.7 | .0 | 2054.2 | 336.2 | -.01 |
| 26A | 15.00 | -476.4 | .0 | 12538.6 | .0 | 249.7 | .00 |
| 28 | 97.44? | .0 | -3.4 | .0 | 1031.3 | 336.2 | -.06 |
| 28A | 15.00 | -283.3 | .0 | 7456.3 | .0 | 249.7 | .00 |
| B2C | 98.71? | .0 | -55.0 | .0 | 16950.7 | 337.0 | -.40 |
| 611 | 98.66? | .0 | -5.7 | .0 | 1764.9 | 337.0 | -.07 |
| 611A | 15.00 | -151.3 | .0 | 3982.1 | .0 | 249.7 | .00 |
| B2A | 98.33? | .0 | -66.4 | .0 | 20445.3 | 336.8 | .08 |
| 610 | 98.25? | .0 | -10.1 | .0 | 3108.1 | 336.7 | -.07 |
| 610A | 15.00 | -158.4 | .0 | 4169.0 | .0 | 249.7 | .00 |
| 613 | 98.00? | .0 | -49.3 | .0 | 15152.7 | 336.6 | -1.08 |
| 613A | 15.00 | -1602.7 | .0 | 42182.1 | .0 | 249.7 | .00 |
| 615 | 97.88? | .0 | -12.1 | .0 | 3718.3 | 336.5 | -.18 |
| 615A | 15.00 | -1602.7 | .0 | 42182.1 | .0 | 249.7 | .00 |
| 614 | 97.08? | .0 | -113.1 | .0 | 34734.2 | 336.0 | 3.89 |
| 614A | 15.00 | -108.5 | .0 | 2855.7 | .0 | 249.7 | .00 |
| 618 | 96.91? | .0 | -104.1 | .0 | 31955.0 | 335.8 | -2.90 |
| 618A | 15.00 | -352.2 | .0 | 9269.7 | .0 | 249.7 | .00 |
| B3 | 97.74? | .0 | -196.2 | .0 | 60314.5 | 336.4 | -.19 |
| B3A | 77.[illegible]4? | .0 | -146.2 | .0 | 42705.4 | 321.6 | -.21 |
| 671 | 72.[illegible]5? | .0 | -191.2 | .0 | 55061.1 | 317.7 | .17 |
| 671A | 15.00 | -1058.9 | .0 | 27869.6 | .0 | 249.7 | .00 |
| 672 | 70.80? | .0 | -95.7 | .0 | 27461.4 | 316.7 | -.16 |
| 672A | 15.00 | -1058.9 | .0 | 27869.6 | .0 | 249.7 | .00 |
| 670 | 76.58? | .0 | -20.3 | .0 | 5931.4 | 321.3 | .22 |
| 670A | 15.00 | -1058.9 | .0 | 27869.6 | .0 | 249.7 | .00 |
| 669 | 73.91? | .0 | -32.7 | .0 | 9458.0 | 319.2 | -.01 |
| 669A | 15.00 | -353.8 | .0 | 9311.8 | .0 | 249.7 | .00 |
| 668 | 72.12? | .0 | -30.9 | .0 | 8905.3 | 317.7 | .01 |
| 668A | 15.00 | -1058.9 | .0 | 27869.6 | .0 | 249.7 | .00 |
| 667 | 70.85? | .0 | -30.6 | .0 | 8795.1 | 316.7 | .03 |
| 667A | 15.00 | -1058.9 | .0 | 27869.6 | .0 | 249.7 | .00 |
| B3B | 70.27? | .0 | -21.6 | .0 | 6192.1 | 316.2 | -.15 |
| 622 | 70.19? | .0 | -4.3 | .0 | 1233.1 | 316.2 | -.02 |
| 622A | 15.00 | -63.8 | .0 | 1679.2 | .0 | 249.7 | .00 |
| 666 | 70.17? | .0 | -18.1 | .0 | 5173.5 | 316.1 | .15 |
| 666A | 15.00 | -1058.9 | .0 | 27869.6 | .0 | 249.7 | .00 |
| 665 | 69.97? | .0 | -22.1 | .0 | 6315.2 | 316.0 | -.02 |
| 665A | 15.00 | -172.8 | .0 | 4548.0 | .0 | 249.7 | .00 |
| B3C | 69.90? | .0 | -10.9 | .0 | 3115.4 | 315.9 | -.17 |
| 624 | 69.78? | .0 | -3.7 | .0 | 1053.2 | 315.8 | .00 |

COMPUTED NODE DATA

| NODE NAME | PRESSURE ( psig ) | NODE FLOW (lbm/hr) | CONDS FLOW (lbm/hr) | FLOW LOSS (Btu/hr ) | CONDS LOSS (Btu/hr ) | TEMP (F) | RESIDUAL (lbm/hr) |
|---|---|---|---|---|---|---|---|
| 624A | 15.00 | -49.8 | .0 | 1310.7 | .0 | 249.7 | .00 |
| 623 | 69.71? | .0 | -2.1 | .0 | 614.4 | 315.8 | -.02 |
| 623A | 15.00 | -90.8 | .0 | 2389.8 | .0 | 249.7 | .00 |
| 664 | 68.86? | .0 | -7.6 | .0 | 2170.1 | 315.1 | .09 |
| 664A | 15.00 | -174.3 | .0 | 4587.5 | .0 | 249.7 | .00 |
| 663 | 67.18? | .0 | -10.7 | .0 | 3048.9 | 313.7 | .00 |
| 663A | 15.00 | -286.4 | .0 | 7537.9 | .0 | 249.7 | .00 |
| 662 | 66.34? | .0 | -5.4 | .0 | 1541.8 | 312.9 | -.07 |
| 662A | 15.00 | -621.7 | .0 | 16362.8 | .0 | 249.7 | .0[illegible] |
| B4 | 97.49? | .0 | -141.2 | .0 | 43376.9 | 336.2 | .[illegible] |
| 604 | 97.04? | .0 | -13.1 | .0 | 4016.5 | 335.9 | -.[illegible] |
| 604A | 15.00 | -102.8 | .0 | 2705.6 | .0 | 249.7 | .0[illegible] |
| B5 | 97.24? | .0 | -184.3 | .0 | 56605.7 | 336.1 | .30 |
| 600 | 96.94? | .0 | -17.1 | .0 | 5243.6 | 335.9 | -.16 |
| 600A | 15.00 | -882.7 | .0 | 23232.2 | .0 | 249.7 | .00 |
| B6 | 96.95? | .0 | -312.8 | .0 | 95996.0 | 335.9 | -.28 |
| B6A | 96.86? | .0 | -52.9 | .0 | 16232.8 | 335.8 | .54 |
| 402 | 96.65? | .0 | -6.0 | .0 | 1843.1 | 335.7 | -.08 |
| 402A | 15.00 | -1278.5 | .0 | 33649.4 | .0 | 249.7 | .00 |
| B7 | 96.80? | .0 | -151.4 | .0 | 46439.3 | 335.8 | -.69 |
| 401 | 96.16? | .0 | -5.9 | .0 | 1808.1 | 335.4 | -.10 |
| 401A | 15.00 | -2277.7 | .0 | 59947.8 | .0 | 249.7 | .00 |
| 400 | 95.99? | .0 | -89.8 | .0 | 27499.4 | 335.2 | .28 |
| 400A | 15.00 | -5907.6 | .0 | 155484.7 | .0 | 249.7 | .00 |
| B8 | 96.83? | .0 | -291.3 | .0 | 89381.5 | 335.8 | -16.5[illegible] |
| B8A | 96.82? | .0 | -112.1 | .0 | 34399.0 | 335.8 | 15.6[illegible] |
| 502 | 96.48? | .0 | -14.7 | .0 | 4516.8 | 335.6 | -.1[illegible] |
| 502A | 15.00 | -273.9 | .0 | 7208.9 | .0 | 249.7 | .00 |
| 500 | 96.81? | .0 | -58.7 | .0 | 17998.7 | 335.8 | -.20 |
| 500A | 15.00 | -724.1 | .0 | 19057.9 | .0 | 249.7 | .00 |
| B9 | 96.78? | .0 | -75.1 | .0 | 23032.6 | 335.8 | .60 |
| 538 | 96.76? | .0 | -29.3 | .0 | 8996.6 | 335.8 | -.43 |
| 538A | 15.00 | -482.8 | .0 | 12707.0 | .0 | 249.7 | .00 |
| 537 | 96.76? | .0 | -43.4 | .0 | 13315.4 | 335.7 | .32 |
| 537A | 15.00 | -581.9 | .0 | 15315.3 | .0 | 249.7 | .00 |
| 539 | 96.75? | .0 | -28.2 | .0 | 8637.0 | 335.7 | -.10 |
| 539A | 15.00 | -581.9 | .0 | 15315.3 | .0 | 249.7 | .00 |
| D1 | 99.94? | .0 | -154.2 | .0 | 47643.7 | 337.8 | .00 |
| D1A | 99.37? | .0 | -217.6 | .0 | 67139.9 | 337.5 | -1.00 |
| C1 | 99.32? | .0 | -106.7 | .0 | 32929.2 | 337.4 | -.01 |
| 19 | 96.16? | .0 | -2.1 | .0 | 636.2 | 335.4 | -.04 |
| 19A | 15.00 | -1639.6 | .0 | 43153.3 | .0 | 249.7 | .00 |
| 31 | 98.98? | .0 | -125.8 | .0 | 38794.2 | 337.2 | -.86 |
| 31A | 15.00 | -544.1 | .0 | 14320.4 | .0 | 249.7 | .00 |
| C3 | 98.88? | .0 | -95.1 | .0 | 29324.6 | 337.1 | .29 |
| 32 | 98.87? | .0 | -10.1 | .0 | 3117.9 | 337.1 | .00 |
| 32A | 15.00 | -368.9 | .0 | 9709.2 | .0 | 249.7 | .00 |
| 35 | 98.88? | .0 | -10.1 | .0 | 3118.1 | 337.1 | .12 |
| 35A | 15.00 | -83.9 | .0 | 2208.2 | .0 | 249.7 | .00 |
| C4 | 98.29? | .0 | -71.2 | .0 | 21930.5 | 336.8 | -.03 |
| 427 | 97.80? | .0 | -3.2 | .0 | 975.4 | 336.4 | -.08 |
| 427A | 15.00 | -550.8 | .0 | 14496.7 | .0 | 249.7 | .00 |
| C5 | 97.99? | .0 | -51.9 | .0 | 15975.6 | 336.6 | -.14 |
| 410 | 97.44? | .0 | -31.6 | .0 | 9718.1 | 336.2 | -.71 |

COMPUTED NODE DATA

| NODE NAME | PRESSURE ( psig ) | NODE FLOW (lbm/hr) | CONDS FLOW (lbm/hr) | FLOW LOSS (Btu/hr ) | CONDS LOSS (Btu/hr ) | TEMP (F) | RESIDUAL (lbm/hr) |
|---|---|---|---|---|---|---|---|
| 410A | 15.00 | -1147.1 | .0 | 30191.0 | .0 | 249.7 | .00 |
| C7 | 97.10? | .0 | -49.1 | .0 | 15074.0 | 336.0 | .92 |
| 421 | 96.99? | .0 | -13.4 | .0 | 4109.0 | 335.9 | -.03 |
| 421A | 15.00 | -859.1 | .0 | 22611.0 | .0 | 249.7 | .00 |
| 420 | 96.83? | .0 | -6.4 | .0 | 1951.2 | 335.8 | -.13 |
| 420A | 15.00 | -859.1 | .0 | 22611.0 | .0 | 249.7 | .00 |
| C8 | 93.51? | .0 | -30.8 | .0 | 9379.6 | 333.6 | .23 |
| 424 | 93.12? | .0 | -5.6 | .0 | 1706.3 | 333.3 | -.02 |
| 424A | 15.00 | -302.3 | .0 | 7956.4 | .0 | 249.7 | .00 |
| 423 | 93.00? | .0 | -5.0 | .0 | 1510.7 | 333.2 | .02 |
| 423A | 15.00 | -97.9 | .0 | 2576.7 | .0 | 249.7 | .00 |
| 422 | 92.94? | .0 | -2.3 | .0 | 705.2 | 333.2 | -.06 |
| 422A | 15.00 | -290.9 | .0 | 7656.3 | .0 | 249.7 | .00 |
| 425 | 93.42? | .0 | -7.6 | .0 | 2322.8 | 333.5 | .02 |
| 425A | 15.00 | -194.3 | .0 | 5113.9 | .0 | 249.7 | .00 |
| 426 | 93.35? | .0 | -5.6 | .0 | 1717.1 | 333.5 | -.07 |
| 426A | 15.00 | -194.3 | .0 | 5113.9 | .0 | 249.7 | .00 |
| 428 | 91.44? | .0 | -21.7 | .0 | 6576.9 | 332.1 | -.03 |
| 428A | 15.00 | -111.1 | .0 | 2924.1 | .0 | 249.7 | .00 |
| C9 | 90.76? | .0 | -21.6 | .0 | 6522.4 | 331.7 | .00 |
| C10 | 89.85? | .0 | -31.4 | .0 | 9485.6 | 331.0 | -.13 |
| C11 | 88.58? | .0 | -19.8 | .0 | 5963.9 | 330.2 | -.11 |
| 429 | 90.29? | .0 | -5.6 | .0 | 1686.7 | 331.4 | .04 |
| 429A | 15.00 | -274.3 | .0 | 7219.4 | .0 | 249.7 | .0[illegible] |
| 432 | 88.33? | .0 | -2.9 | .0 | 883.1 | 330.0 | .[illegible] |
| 432A | 15.00 | -274.3 | .0 | 7219.4 | .0 | 249.7 | .0[illegible] |
| 430 | 87.37? | .0 | -13.3 | .0 | 4005.4 | 329.3 | .02 |
| 430A | 15.00 | -274.3 | .0 | 7219.4 | .0 | 249.7 | .00 |
| 431 | 86.26? | .0 | -11.2 | .0 | 3359.6 | 328.5 | .01 |
| 431A | 15.00 | -544.8 | .0 | 14338.8 | .0 | 249.7 | .00 |
| 434 | 88.75? | .0 | -25.7 | .0 | 7728.5 | 330.3 | .00 |
| 434A | 15.00 | -260.8 | .0 | 6864.1 | .0 | 249.7 | .00 |
| 40 | 87.38? | .0 | -30.3 | .0 | 9082.9 | 329.3 | .11 |
| 40A | 15.00 | -219.3 | .0 | 5771.9 | .0 | 249.7 | .00 |
| 39 | 87.17? | .0 | -11.1 | .0 | 3320.8 | 329.2 | -.08 |
| 39A | 15.00 | -230.6 | .0 | 6069.3 | .0 | 249.7 | .00 |
| D2 | 99.03? | .0 | -160.6 | .0 | 49511.6 | 337.2 | 2.49 |
| D3 | 98.57? | .0 | -243.0 | .0 | 74859.1 | 336.9 | .04 |
| 20 | 98.25? | .0 | -11.1 | .0 | 3412.2 | 336.7 | -.15 |
| 20A | 15.00 | -942.6 | .0 | 24808.7 | .0 | 249.7 | .00 |
| D4 | 97.97? | .0 | -200.2 | .0 | 61596.9 | 336.5 | -.39 |
| D5 | 97.71? | .0 | -163.5 | .0 | 50267.5 | 336.4 | .34 |
| 101 | 97.65? | .0 | -4.4 | .0 | 1341.8 | 336.3 | -.09 |
| 101A | 15.00 | -655.7 | .0 | 17257.7 | .0 | 249.7 | .00 |
| D6 | 97.34? | .0 | -220.5 | .0 | 67729.6 | 336.1 | .28 |
| 51 | 97.06? | .0 | -16.1 | .0 | 4936.7 | 336.0 | -.30 |
| 51A | 15.00 | -213.7 | .0 | 5624.5 | .0 | 249.7 | .00 |
| 472 | 97.00? | .0 | -5.0 | .0 | 1543.2 | 335.9 | .13 |
| 472A | 15.00 | -627.7 | .0 | 16520.7 | .0 | 249.7 | .00 |
| D7 | 96.98? | .0 | -172.4 | .0 | 52904.9 | 335.9 | -.17 |
| D7A | 96.60? | .0 | -63.4 | .0 | 19434.2 | 335.6 | .40 |
| 456 | 96.59? | .0 | -4.5 | .0 | 1386.4 | 335.6 | -.18 |
| 456A | 15.00 | -1528.3 | .0 | 40224.0 | .0 | 249.7 | .00 |
| 455 | 96.58? | .0 | -1.2 | .0 | 359.5 | 335.6 | .00 |

COMPUTED NODE DATA

| NODE NAME | PRESSURE ( psig ) | NODE FLOW (lbm/hr) | CONDS FLOW (lbm/hr) | FLOW LOSS (Btu/hr ) | CONDS LOSS (Btu/hr ) | TEMP (F) | RESIDUAL (lbm/hr) |
|---|---|---|---|---|---|---|---|
| 455A | 15.00 | -119.4 | .0 | 3142.5 | .0 | 249.7 | .00 |
| 458 | 96.59? | .0 | -4.5 | .0 | 1386.4 | 335.6 | -.18 |
| 458A | 15.00 | -1528.3 | .0 | 40224.0 | .0 | 249.7 | .00 |
| 457 | 96.58? | .0 | -1.2 | .0 | 359.5 | 335.6 | .00 |
| 457A | 15.00 | -119.4 | .0 | 3142.5 | .0 | 249.7 | .00 |
| D7B | 96.41? | .0 | -44.8 | .0 | 13737.4 | 335.5 | .00 |
| 444 | 96.39? | .0 | -4.5 | .0 | 1385.0 | 335.5 | .85 |
| 444A | 15.00 | -1528.3 | .0 | 40224.0 | .0 | 249.7 | -.61 |
| 443 | 96.38? | .0 | -1.2 | .0 | 359.2 | 335.5 | .00 |
| 443A | 15.00 | -119.4 | .0 | 3142.5 | .0 | 249.7 | -.02 |
| 446 | 96.39? | .0 | -4.5 | .0 | 1385.0 | 335.5 | .00 |
| 446A | 15.00 | -1528.3 | .0 | 40224.0 | .0 | 249.7 | -.61 |
| 445 | 96.38? | .0 | -1.2 | .0 | 359.2 | 335.5 | .00 |
| 445A | 15.00 | -119.4 | .0 | 3142.5 | .0 | 249.7 | -.02 |
| D8 | 96.83? | .0 | -138.8 | .0 | 42594.6 | 335.8 | .00 |
| D9 | 96.50? | .0 | -243.4 | .0 | 74632.7 | 335.6 | .42 |
| 126 | 96.50? | .0 | -44.4 | .0 | 13606.4 | 335.6 | 785.42 |
| 126A | 15.00 | -1425.8 | .0 | 37526.2 | .0 | 249.7 | -787.41 |
| D10 | 96.32? | .0 | -126.3 | .0 | 38707.9 | 335.5 | .00 |
| 300 | 96.28? | .0 | -23.4 | .0 | 7175.7 | 335.4 | 1.39 |
| 300A | 15.00 | -4339.6 | .0 | 114215.8 | .0 | 249.7 | -.33 |
| | | | | | | | .00 |

COMPUTED PIPE FLOWS AND PARAMETERS

| FROM NODE | TO NODE | STATUS | FLOW (lbm/hr) | CONDENSATE (lbm/hr) | HEAT LOSS (Btu/hr ) | DIAMETER (in) | RE NUMBER | FRIC FACTOR |
|---|---|---|---|---|---|---|---|---|
| 2 | A1 | | 13211.6 | 282.26 | 250027.2 | 7.98 | 5.13E+5 | 1.66E-2 |
| A1 | 1 | | 12944.8 | 234.87 | 208067.8 | 7.98 | 5.03E+5 | 1.66E-2 |
| 2 | B1 | | 24774.6 | 95.37 | 85163.4 | 10.02 | 7.66E+5 | 1.57E-2 |
| B1 | B2 | | 24617.9 | 197.79 | 176687.7 | 10.02 | 7.61E+5 | 1.57E-2 |
| B2 | B2B | | 632.6 | 45.87 | 40422.6 | 4.03 | 4.86E+4 | 2.31E-2 |
| B2B | 13 | | 322.5 | 7.41 | 6538.0 | 2.07 | 4.83E+4 | 2.50E-2 |
| B2B | 17 | | 262.6 | 8.09 | 7132.5 | 2.07 | 3.93E+4 | 2.57E-2 |
| B2 | 18 | | 923.0 | 9.95 | 8907.2 | 2.07 | 1.38E+5 | 2.28E-2 |
| 18 | 26 | | 783.6 | 6.66 | 5928.3 | 2.07 | 1.17E+5 | 2.31E-2 |
| 26 | 28 | | 293.6 | 6.71 | 5924.5 | 2.07 | 4.39E+4 | 2.53E-2 |
| B2 | B2C | | 4448.6 | 42.25 | 37439.2 | 5.05 | 2.73E+5 | 1.86E-2 |
| B2C | 611 | | 164.0 | 11.46 | 10098.7 | 2.07 | 2.45E+4 | 2.76E-2 |
| B2C | B2A | | 4224.4 | 56.32 | 49881.4 | 5.05 | 2.59E+5 | 1.87E-2 |
| B2A | 610 | | 175.4 | 20.20 | 17805.7 | 2.07 | 2.63E+4 | 2.73E-2 |
| B2A | 613 | | 3974.6 | 56.31 | 49842.4 | 5.05 | 2.44E+5 | 1.88E-2 |
| 613 | 615 | | 1621.6 | 24.18 | 21350.3 | 4.03 | 1.25E+5 | 2.05E-2 |
| 613 | 614 | | 695.1 | 18.03 | 15998.4 | 2.07 | 1.04E+5 | 2.03E-2 |
| 614 | 618 | | 460.4 | 208.26 | 183757.0 | 3.07 | 4.65E+4 | 2.40E-2 |
| B2 | B3 | | 18377.3 | 168.70 | 152268.3 | 7.98 | 7.13E+5 | 1.63E-2 |
| B3 | B3A | | 8914.9 | 97.05 | 118141.3 | 4.03 | 6.85E+5 | 1.87E-2 |
| B3A | 671 | | 2416.2 | 190.98 | 173694.0 | 3.07 | 2.44E+5 | 2.05E-2 |
| 671 | 672 | | 1160.1 | 191.43 | 172127.4 | 3.07 | 1.17E+5 | 2.15E-2 |
| B3A | 670 | | 6347.7 | 4.40 | 4503.3 | 4.03 | 4.88E+5 | 1.89E-2 |
| 670 | 669 | | 5262.2 | 36.27 | 35275.5 | 4.03 | 4.05E+5 | 1.90E-2 |
| 669 | 668 | | 4869.9 | 29.07 | 27846.5 | 4.03 | 3.74E+5 | 1.91E-2 |
| 668 | 667 | | 3774.4 | 32.77 | 30418.4 | 4.03 | 2.90E+5 | 1.93E-2 |
| 667 | B3B | | 2679.1 | 28.53 | 25947.1 | 4.03 | 2.06E+5 | 1.97E-2 |
| B3B | 622 | | 73.7 | 8.61 | 7733.7 | 1.38 | 1.66E+4 | 3.07E-2 |
| B3B | 666 | | 2579.2 | 6.09 | 5523.8 | 4.03 | 1.98E+5 | 1.98E-2 |
| 666 | 665 | | 1496.4 | 30.05 | 27047.0 | 4.03 | 1.15E+5 | 2.07E-2 |
| 665 | B3C | | 1295.9 | 14.09 | 12670.0 | 4.03 | 9.96E+4 | 2.10E-2 |
| B3C | 624 | | 157.7 | 3.07 | 2758.8 | 1.38 | 3.54E+4 | 2.76E-2 |
| 624 | 623 | | 98.6 | 4.30 | 3861.2 | 1.38 | 2.21E+4 | 2.93E- |
| B3C | 664 | | 1122.8 | 4.62 | 4408.0 | 2.07 | 1.68E+5 | 2.26E- |
| 664 | 663 | | 935.2 | 10.59 | 9877.1 | 2.07 | 1.40E+5 | 2.28E-2 |
| 663 | 662 | | 632.5 | 10.89 | 9929.3 | 2.07 | 9.47E+4 | 2.34E-2 |
| B3 | B4 | | 9258.2 | 126.60 | 112007.1 | 7.98 | 3.59E+5 | 1.70E-2 |
| B4 | 604 | | 122.8 | 26.17 | 23094.7 | 1.38 | 2.76E+4 | 2.84E-2 |
| B4 | B5 | | 8985.9 | 129.56 | 114611.1 | 7.98 | 3.49E+5 | 1.70E-2 |
| B5 | 600 | | 906.6 | 34.17 | 30189.3 | 3.07 | 9.15E+4 | 2.20E-2 |
| B5 | B6 | | 7886.5 | 204.90 | 181136.0 | 7.98 | 3.06E+5 | 1.72E-2 |
| B6 | B6A | | 4210.8 | 37.49 | 33134.9 | 6.07 | 2.15E+5 | 1.84E-2 |
| B6A | 402 | | 1291.4 | 12.02 | 10647.0 | 3.07 | 1.30E+5 | 2.14E-2 |
| B6A | B7 | | 2858.2 | 56.29 | 49694.2 | 6.07 | 1.46E+5 | 1.91E-2 |
| B7 | 401 | | 2290.4 | 11.80 | 10640.4 | 3.07 | 2.31E+5 | 2.06E-2 |
| B7 | 400 | | 6004.6 | 179.59 | 159280.2 | 6.07 | 3.06E+5 | 1.79E-2 |
| B7 | C7 | | -5595.2 | 55.04 | 48819.9 | 6.07 | 2.86E+5 | 1.80E-2 |
| B6 | B8 | | 3355.0 | 383.18 | 338143.3 | 7.98 | 1.30E+5 | 1.87E-2 |
| B8 | B8A | | 1220.6 | 77.44 | 68328.9 | 6.07 | 6.23E+4 | 2.14E-2 |
| B8A | 502 | | 295.5 | 29.47 | 26019.6 | 2.07 | 4.42E+4 | 2.53E |
| B8A | 500 | | 789.5 | 117.33 | 103525.3 | 6.07 | 4.03E+4 | 2.32E |
| B8 | B9 | | 1851.5 | 122.00 | 107664.8 | 6.07 | 9.45E+4 | 2.01E- |
| B9 | 538 | | 1768.1 | 28.15 | 24843.8 | 6.07 | 9.02E+4 | 2.03E-2 |
| 538 | 537 | | 1249.4 | 30.50 | 26913.5 | 6.07 | 6.38E+4 | 2.13E-2 |

COMPUTED PIPE FLOWS AND PARAMETERS

| FROM NODE | TO NODE | STATUS | FLOW (lbm/hr) | CONDENSATE (lbm/hr) | HEAT LOSS (Btu/hr ) | DIAMETER (in) | RE NUMBER | FRIC FACTOR |
|---|---|---|---|---|---|---|---|---|
| 537 | 539 | | 616.9 | 56.31 | 49685.9 | 6.07 | 3.15E+4 | 2.43E-2 |
| 2 | D1 | | 33250.3 | 30.43 | 27105.1 | 11.94 | 8.63E+5 | 1.51E-2 |
| D1 | D1A | | 33085.5 | 277.98 | 247647.5 | 11.94 | 8.58E+5 | 1.51E-2 |
| D1A | C1 | | 15962.3 | 21.14 | 18739.5 | 10.02 | 4.94E+5 | 1.60E-2 |
| C1 | 19 | | 1648.5 | 4.15 | 4446.1 | 2.07 | 2.47E+5 | 2.22E-2 |
| C1 | 31 | | 14198.0 | 188.16 | 166503.1 | 10.02 | 4.39E+5 | 1.62E-2 |
| 31 | C3 | | 13518.4 | 63.50 | 56167.6 | 10.02 | 4.18E+5 | 1.62E-2 |
| C3 | 32 | | 386.1 | 20.23 | 17828.8 | 4.03 | 2.97E+4 | 2.52E-2 |
| C3 | 35 | | 101.2 | 20.23 | 17828.9 | 4.03 | 7.78E+3 | 3.41E-2 |
| C3 | C4 | | 12927.5 | 86.31 | 77208.9 | 7.98 | 5.02E+5 | 1.66E-2 |
| C4 | 427 | | 560.9 | 6.34 | 5635.5 | 2.07 | 8.39E+4 | 2.37E-2 |
| C4 | C5 | | 12287.1 | 49.83 | 44499.6 | 7.98 | 4.77E+5 | 1.67E-2 |
| C5 | 410 | | 8592.7 | 34.16 | 30824.0 | 6.07 | 4.39E+5 | 1.75E-2 |
| 410 | C7 | | 7405.1 | 29.10 | 26056.1 | 6.07 | 3.78E+5 | 1.77E-2 |
| C7 | 421 | | 1751.7 | 14.06 | 12429.6 | 4.03 | 1.35E+5 | 2.04E-2 |
| 421 | 420 | | 872.3 | 12.72 | 11242.4 | 3.07 | 8.80E+4 | 2.21E-2 |
| C5 | C8 | | 3634.4 | 19.88 | 20066.1 | 3.07 | 3.67E+5 | 2.02E-2 |
| C8 | 424 | | 724.2 | 5.92 | 5281.9 | 2.07 | 1.08E+5 | 2.32E-2 |
| 424 | 423 | | 409.5 | 5.30 | 4692.2 | 2.07 | 6.13E+4 | 2.44E-2 |
| 423 | 422 | | 299.9 | 4.64 | 4104.8 | 2.07 | 4.49E+4 | 2.53E-2 |
| C8 | 425 | | 415.4 | 3.98 | 3522.5 | 2.07 | 6.22E+4 | 2.43E-2 |
| 425 | 426 | | 206.6 | 11.28 | 9978.5 | 2.07 | 3.09E+4 | 2.66E-2 |
| C8 | 428 | | 2457.3 | 31.83 | 28993.8 | 3.07 | 2.48E+5 | 2.05E-2 |
| 428 | C9 | | 2316.7 | 11.58 | 10509.0 | 3.07 | 2.34E+5 | 2.06E-2 |
| C9 | 429 | | 286.5 | 11.16 | 9911.6 | 1.61 | 5.51E+4 | 2.56E-2 |
| C9 | C10 | | 2002.3 | 20.38 | 18356.1 | 3.07 | 2.02E+5 | 2.07E-2 |
| C10 | C11 | | 602.8 | 7.06 | 6393.3 | 1.61 | 1.16E+5 | 2.43E-2 |
| C11 | 432 | | 283.8 | 5.87 | 5221.2 | 1.61 | 5.46E+4 | 2.57E-2 |
| C11 | 430 | | 294.2 | 26.70 | 23757.7 | 1.61 | 5.66E+4 | 2.56E-2 |
| C10 | 431 | | 562.5 | 22.46 | 20285.7 | 1.61 | 1.08E+5 | 2.44E-2 |
| C10 | 434 | | 799.5 | 12.95 | 11626.6 | 2.07 | 1.20E+5 | 2.31E-2 |
| 434 | 40 | | 505.7 | 38.40 | 34195.8 | 2.07 | 7.57E+4 | 2.39E-2 |
| 40 | 39 | | 248.8 | 22.15 | 19668.0 | 2.07 | 3.72E+4 | 2.59E-2 |
| D1A | D2 | | 16901.0 | 136.04 | 120726.7 | 10.02 | 5.23E+5 | 1.60E-2 |
| D2 | D3 | | 16728.1 | 185.11 | 164293.3 | 10.02 | 5.17E+5 | 1.60E-2 |
| D3 | 20 | | 960.5 | 22.17 | 19591.3 | 3.07 | 9.69E+4 | 2.19E-2 |
| D3 | D4 | | 15514.7 | 278.78 | 247190.7 | 10.02 | 4.80E+5 | 1.61E-2 |
| D4 | D5 | | 15305.1 | 121.71 | 107913.5 | 10.02 | 4.73E+5 | 1.61E-2 |
| D5 | 101 | | 667.0 | 8.73 | 7705.4 | 3.07 | 6.73E+4 | 2.28E-2 |
| D5 | D6 | | 14464.6 | 196.58 | 174200.0 | 10.02 | 4.47E+5 | 1.61E-2 |
| D6 | 51 | | 877.4 | 22.11 | 19539.0 | 3.07 | 8.85E+4 | 2.21E-2 |
| 51 | 472 | | 639.8 | 10.06 | 8877.9 | 3.07 | 6.46E+4 | 2.29E-2 |
| D6 | D7 | | 13356.7 | 222.30 | 196850.5 | 10.02 | 4.13E+5 | 1.62E-2 |
| D7 | D7A | | 6793.1 | 37.11 | 33126.5 | 6.07 | 3.47E+5 | 1.78E-2 |
| D7A | 456 | | 1667.1 | 6.70 | 5912.9 | 5.05 | 1.02E+5 | 2.03E-2 |
| 456 | 455 | | 127.5 | 2.34 | 2069.5 | 2.07 | 1.91E+4 | 2.89E-2 |
| D7A | 458 | | 1667.1 | 6.70 | 5912.9 | 5.05 | 1.02E+5 | 2.03E-2 |
| 458 | 457 | | 127.5 | 2.34 | 2069.5 | 2.07 | 1.91E+4 | 2.89E-2 |
| D7A | D7B | | 3387.0 | 76.24 | 67392.9 | 6.07 | 1.73E+5 | 1.88E-2 |
| D7B | 444 | | 1666.6 | 6.69 | 5910.3 | 5.05 | 1.02E+5 | 2.03E-2 |
| 444 | 443 | | 127.5 | 2.34 | 2068.5 | 2.07 | 1.91E+4 | 2.89E-2 |
| D7B | 446 | | 1666.6 | 6.69 | 5910.3 | 5.05 | 1.02E+5 | 2.03E-2 |
| 446 | 445 | | 127.5 | 2.34 | 2068.5 | 2.07 | 1.91E+4 | 2.89E-2 |
| D7 | D8 | | 6381.8 | 85.34 | 75440.8 | 7.98 | 2.48E+5 | 1.75E-2 |

COMPUTED PIPE FLOWS AND PARAMETERS

| FROM NODE | TO NODE | STATUS | FLOW (lbm/hr) | CONDENSATE (lbm/hr) | HEAT LOSS (Btu/hr ) | DIAMETER (in) | RE NUMBER | FRIC FACTOR |
|---|---|---|---|---|---|---|---|---|
| D8 | D9 | | 6233.6 | 192.31 | 170021.6 | 7.98 | 2.42E+5 | 1.75E-2 |
| D9 | 126 | | 689.7 | 88.76 | 78329.1 | 7.98 | 2.68E+4 | 1.92E-2 |
| D9 | D10 | | 4506.2 | 205.77 | 181744.9 | 7.98 | 1.75E+5 | 1.81E-2 |
| D10 | 300 | | 4369.6 | 46.83 | 41362.3 | 7.98 | 1.70E+5 | 1.81E-2 |

COMPUTED VALVE AND REGULATOR FLOWS AND PARAMETERS

| FROM NODE | TO NODE | STATUS | FLOW (lbm/hr) | Cs |
|---|---|---|---|---|
| 1 | 1A | ? | 12821.2 | 113.7 |
| 13 | 13A | ? | 315.3 | 2.8 |
| 17 | 17A | ? | 254.3 | 2.3 |
| 18 | 18A | ? | 125.5 | 1.1 |
| 26 | 26A | ? | 477.8 | 4.3 |
| 28 | 28A | ? | 284.7 | 2.6 |
| 611 | 611A | ? | 152.7 | 1.4 |
| 610 | 610A | ? | 159.8 | 1.4 |
| 613 | 613A | ? | 1604.1 | 14.3 |
| 615 | 615A | ? | 1604.1 | 14.3 |
| 614 | 614A | ? | 109.9 | 1.0 |
| 618 | 618A | ? | 353.6 | 3.2 |
| 671 | 671A | ? | 1060.3 | 12.4 |
| 672 | 672A | ? | 1060.3 | 12.6 |
| 670 | 670A | ? | 1060.3 | 11.8 |
| 669 | 669A | ? | 355.2 | 4.1 |
| 668 | 668A | ? | 1060.3 | 12.4 |
| 667 | 667A | ? | 1060.3 | 12.6 |
| 622 | 622A | ? | 65.2 | .8 |
| 666 | 666A | ? | 1060.3 | 12.7 |
| 665 | 665A | ? | 174.2 | 2.1 |
| 624 | 624A | ? | 51.2 | .6 |
| 623 | 623A | ? | 92.2 | 1.1 |
| 664 | 664A | ? | 175.7 | 2.1 |
| 663 | 663A | ? | 287.8 | 3.6 |
| 662 | 662A | ? | 623.1 | 7.9 |
| 604 | 604A | ? | 104.2 | .9 |
| 600 | 600A | ? | 884.1 | 8.0 |
| 402 | 402A | ? | 1279.9 | 11.6 |
| 401 | 401A | ? | 2279.1 | 20.7 |
| 400 | 400A | ? | 5909.0 | 53.7 |
| 502 | 502A | ? | 275.3 | 2.5 |
| 500 | 500A | ? | 725.5 | 6.5 |
| 538 | 538A | ? | 484.2 | 4.4 |
| 537 | 537A | ? | 583.3 | 5.3 |
| 539 | 539A | ? | 583.3 | 5.3 |
| 19 | 19A | ? | 1641.0 | 14.9 |
| 31 | 31A | ? | 545.5 | 4.8 |
| 32 | 32A | ? | 370.3 | 3.3 |
| 35 | 35A | ? | 85.3 | .8 |
| 427 | 427A | ? | 552.2 | 4.9 |
| 410 | 410A | ? | 1148.5 | 10.3 |
| 421 | 421A | ? | 860.5 | 7.8 |
| 420 | 420A | ? | 860.5 | 7.8 |
| 424 | 424A | ? | 303.7 | 2.8 |
| 423 | 423A | ? | 99.3 | .9 |
| 422 | 422A | ? | 292.3 | 2.7 |
| 425 | 425A | ? | 195.7 | 1.8 |
| 426 | 426A | ? | 195.7 | 1.8 |
| 428 | 428A | ? | 112.5 | 1.1 |
| 429 | 429A | ? | 275.7 | 2.6 |
| 432 | 432A | ? | 275.7 | 2.7 |
| 430 | 430A | ? | 275.7 | 2.7 |
| 431 | 431A | ? | 546.2 | 5.5 |

VAULT HEAT AND CONDENSATE LOSSES

| VAULT NUMBER | NODE NAME | HEAT LOSS (Btu/hr ) | CONDENSATE (lbm/hr) | CONDS LOSS (Btu/hr ) |
|---|---|---|---|---|
| 1 | A1 | 2352.1 | 2.7 | 823.7 |
| 2 | B1 | 3026.4 | 3.4 | 1061.0 |
| 3 | B2 | 3025.2 | 3.4 | 1058.6 |
| 4 | B2A | 2014.1 | 2.3 | 703.4 |
| 5 | B2B | 1347.2 | 1.5 | 471.4 |
| 6 | 614 | 2014.5 | 2.3 | 701.0 |
| 7 | B3 | 2353.4 | 2.7 | 820.5 |
| 8 | B3A | 482.1 | .5 | 157.6 |
| 9 | B3B | 474.0 | .5 | 151.2 |
| 10 | B3C | 473.6 | .5 | 150.9 |
| 11 | B4 | 2349.4 | 2.7 | 818.5 |
| 12 | B5 | 2351.1 | 2.7 | 818.5 |
| 13 | B6 | 2346.9 | 2.7 | 816.4 |
| 14 | B6A | 2013.7 | 2.3 | 700.3 |
| 15 | B7 | 2011.1 | 2.3 | 699.3 |
| 16 | B8 | 2347.8 | 2.7 | 816.4 |
| 17 | B8A | 2013.5 | 2.3 | 700.2 |
| 18 | B9 | 2009.2 | 2.3 | 698.6 |
| 19 | C1 | 3028.8 | 3.4 | 1060.7 |
| 20 | 31 | 3031.3 | 3.4 | 1060.6 |
| 21 | C3 | 2353.7 | 2.7 | 823.3 |
| 22 | C4 | 2351.0 | 2.7 | 821.0 |
| 23 | C5 | 2353.1 | 2.7 | 821.0 |
| 24 | 410 | 2350.6 | 2.7 | 818.9 |
| 25 | C7 | 2349.0 | 2.7 | 817.5 |
| 26 | C8 | 999.5 | 1.1 | 344.2 |
| 27 | 428 | 995.2 | 1.1 | 340.6 |
| 28 | C9 | 994.4 | 1.1 | 339.7 |
| 29 | C10 | 991.9 | 1.1 | 337.9 |
| 30 | 434 | 659.7 | .7 | 224.0 |
| 31 | 40 | 657.8 | .7 | 222.4 |
| 32 | 39 | 657.9 | .7 | 222.3 |
| 33 | D1 | 4389.2 | 5.0 | 1539.9 |
| 34 | D2 | 3707.4 | 4.2 | 1297.3 |
| 35 | D3 | 3704.1 | 4.2 | 1294.5 |
| 36 | D4 | 3699.8 | 4.2 | 1290.8 |
| 37 | D5 | 3690.3 | 4.2 | 1286.5 |
| 38 | 51 | 1007.3 | 1.1 | 350.5 |
| 39 | D6 | 3687.6 | 4.2 | 1284.2 |
| 40 | D7 | 3691.5 | 4.2 | 1284.2 |
| 41 | D7A | 2343.2 | 2.7 | 814.3 |
| 42 | D7B | 2343.7 | 2.7 | 814.0 |
| 43 | D8 | 3019.4 | 3.4 | 1050.0 |
| 44 | D9 | 3013.9 | 3.4 | 1047.1 |
| 45 | D10 | 3016.4 | 3.4 | 1047.4 |

COMPUTED VALVE AND REGULATOR FLOWS AND PARAMETERS

| FROM NODE | TO NODE | STATUS | FLOW (lbm/hr) | Cs |
|---|---|---|---|---|
| 434 | 434A | ? | 262.2 | 2.6 |
| 40 | 40A | ? | 220.7 | 2.2 |
| 39 | 39A | ? | 232.0 | 2.3 |
| 20 | 20A | ? | 944.0 | 8.4 |
| 101 | 101A | ? | 657.1 | 5.9 |
| 51 | 51A | ? | 215.1 | 1.9 |
| 472 | 472A | ? | 629.1 | 5.7 |
| 456 | 456A | ? | 1529.7 | 13.8 |
| 455 | 455A | ? | 120.8 | 1.1 |
| 458 | 458A | ? | 1529.7 | 13.8 |
| 457 | 457A | ? | 120.8 | 1.1 |
| 444 | 444A | ? | 1529.7 | 13.9 |
| 443 | 443A | ? | 120.8 | 1.1 |
| 446 | 446A | ? | 1529.7 | 13.9 |
| 445 | 445A | ? | 120.8 | 1.1 |
| 126 | 126A | ? | 1427.2 | 12.9 |
| 300 | 300A | ? | 4341.0 | 39.4 |

COMPUTED TRAP LOSSES

5 percent trap leakage rate

| Trap Steam Losses | Trap Heat Losses |
|---|---|
| 694.3 lbs/hr | 822613.1 Btus/hr |

Ft. Harrison - 100 PSI and 0 deg F

SYSTEM MASS FLOWS

| | | |
|---|---|---|
| (1) | Steam to loads: | 63625. lbm/hr |
| (2) | Steam condensed in pipes: | 7013. lbm/hr |
| (3) | Steam condensed in vaults: | 113. lbm/hr |
| (4) | Steam lost to trap leakage: | 694. lbm/hr |
| (5) | Total steam plant output: | 71446. lbm/hr |
| (6) | Pipe and vault condensate returned: | 0. lbm/hr |
| (7) | Load condensate returned: | 38175. lbm/hr |
| (8) | Total condensate returned: | 38175. lbm/hr |

SYSTEM HEAT LOSSES AND DISTRIBUTION EFFICIENCY
(M = Million)

| | | | |
|---|---|---|---|
| (1) | Total pipe conduction heat losses: | 6.270 MBtus/hr | 56.77 % |
| (2) | Total pipe condensate heat losses: | 2.143 MBtus/hr | 19.40 % |
| (3) | Total load condensate heat losses: | 1.675 MBtus/hr | 15.16 % |
| (4) | Total vault conduction heat losses: | .100 MBtus/hr | .91 % |
| (5) | Total vault condensate heat losses: | .035 MBtus/hr | .32 % |
| (6) | Total trap heat losses: | .823 MBtus/hr | 7.45 % |
| (7) | Total heat losses: | 11.045 MBtus/hr | 100.00 % |
| (8) | Total heat to loads: | 69.839 MBtus/hr | |
| (9) | Total heat input to supply: | 84.994 MBtus/hr | |
| (10) | Total heat returned to plant: | 2.512 MBtus/hr | |
| (11) | Net heat input from plant: | 82.482 MBtus/hr | |

DISTRIBUTION EFFICIENCY: 86.6% [1.0-(7)/(11)]

# APPENDIX B: Fort Benjamin Harrison Building Heating Loads

| Building Number | Use | Steam Line | Area Sq. ft. | Intercept (lb/hr) | Slope (lb/hr/ F) |
|---|---|---|---|---|---|
| 1 | Admin | A | 1584531 | 5266.50 | 116.20 |
| 13 | Whs | B | 16024 | 22.80 | 6.72 |
| 17 | Sply | B | 11916 | 36.40 | 3.33 |
| 18 | Admin | B | 5846 | 17.90 | 1.63 |
| 19 | Commiss | D | 59835 | 552.40 | 16.73 |
| 20 | PX | D | 41235 | 380.70 | 8.65 |
| 26 | Maint | B | 14074 | 77.60 | 5.90 |
| 27 | Maint | B | 465 | 2.60 | 0.20 |
| 28 | Admin | B | 13344 | 40.80 | 3.73 |
| 31 | Lib | D | 25511 | 77.90 | 7.13 |
| 32 | Training | D | 17379 | 53.10 | 4.86 |
| 35 | Crdt Un | D | 3948 | 36.40 | 0.83 |
| 39 | Theater | D | 10090 | 93.10 | 2.12 |
| 40 | Bowling | D | 15344 | 45.00 | 2.68 |
| 51 | Gst Hse | D | 9568 | 31.20 | 2.81 |
| 101 | NCO Club | D | 20527 | 189.50 | 7.17 |
| 126 | Rsv Ctr | D | 67179 | 205.20 | 16.43 |
| 127 | Maint | D | 11541 | 63.60 | 4.03 |
| 300 | Hosp/Dent | D | 109424 | 1108.70 | 49.71 |
| 400 | Training | B | 327374 | 1000.20 | 75.50 |
| 401 | EN Brk | B | 70184 | 364.80 | 29.43 |
| 402 | EM Brk | B | 39396 | 204.80 | 16.52 |
| 410 | EM Dng | D | 31439 | 290.20 | 13.18 |
| 420 | EN Brk | D | 38455 | 125.40 | 11.29 |
| 421 | EN Brk | D | 38455 | 125.40 | 11.29 |
| 422 | Maint | D | 10308 | 56.80 | 4.32 |
| 423 | Vhl Wash | D | 3470 | 19.10 | 1.46 |
| 424 | QM Repair | D | 10711 | 59.00 | 4.49 |
| 425 | Salv/Spls | D | 9919 | 14.10 | 4.16 |
| 426 | Whs | D | 9919 | 14.10 | 4.16 |
| 427 | EN Brk | D | 24657 | 80.40 | 7.24 |
| 428 | Admin | D | 5233 | 16.00 | 1.46 |
| 429 | EM Brk | D | 11300 | 133.20 | 4.74 |
| 430 | EM Brk | D | 11300 | 133.20 | 4.74 |
| 431 | EM Brk | D | 22441 | 264.50 | 9.41 |
| 432 | EN Brk | D | 11300 | 133.20 | 4.74 |
| 434 | Training | D | 12288 | 37.50 | 3.44 |
| 457 | Admin | D | 0 | 0.00 | 0.00 |
| 458 | EM Brk | D | 0 | 0.00 | 0.00 |
| 472 | Phys Fit | D | 43922 | 128.90 | 7.67 |
| 500 | Off Club | B | 22667 | 209.30 | 7.92 |
| 502 | Off Qtr | B | 8437 | 43.90 | 3.54 |

| | | | | | |
|---|---|---|---|---|---|
| 529 | Training | B | 11636 | 35.50 | 2.85 |
| 537 | Off Qtr | B | 26042 | 85.00 | 7.64 |
| 538 | Off Qtr | B | 21611 | 70.50 | 6.34 |
| 539 | Off Qtr | B | 26042 | 85.00 | 7.64 |
| 600 | Post HQ | B | 37583 | 114.80 | 10.51 |
| 601 | Post HQ | B | 4006 | 12.20 | 1.12 |
| 604 | Pump Hse | B | 3728 | 20.50 | 1.04 |
| 605 | Pump Hse | B | 615 | 3.40 | 0.17 |
| 610 | Music Ctr | B | 9564 | 88.30 | 2.01 |
| 611 | Rec Ctr | B | 9065 | 83.70 | 1.90 |
| 613 | EM Brk | B | 49385 | 256.70 | 20.71 |
| 614 | Admin | B | 5111 | 15.60 | 1.43 |
| 615 | EM Brk | B | 49385 | 256.70 | 20.71 |
| 618 | Chapel | B | 16587 | 50.70 | 4.64 |
| 622 | Admin | B | 3004 | 9.20 | 0.84 |
| 623 | Fire Sta | B | 3835 | 21.10 | 1.61 |
| 624 | Fire Sta | B | 2103 | 11.60 | 0.88 |
| 662 | Off Qtr | B | 19157 | 99.60 | 8.03 |
| 663 | Admin | B | 13495 | 41.20 | 3.77 |
| 664 | Admin | B | 8213 | 25.10 | 2.30 |
| 665 | Police | B | 8137 | 24.90 | 2.28 |
| 666 | Off Qtr | B | 32630 | 169.60 | 13.68 |
| 667 | Off Qtr | B | 32630 | 169.60 | 13.68 |
| 668 | EN Brk | B | 32630 | 169.60 | 13.68 |
| 669 | NCO Dug | B | 11075 | 102.20 | 3.87 |
| 670 | EM Brk | B | 32630 | 169.60 | 13.68 |
| 671 | Off Qtr | B | 32630 | 169.60 | 13.68 |
| 672 | Off Qtr | B | 32630 | 169.60 | 13.68 |
| | Totals | | 3336115 | 14286.5 | 685.9 |

**APPENDIX C: Equipment Specifications and Instrumentation Configuration Parameters**

ATTACHMENT I

**Fisher Controls Company**
M A R S H A L L T O W N , I O W A

Customer: *Fort Benjamin Harrison*
Reference: 
Order No. 
Quote No. 
Date ______ Page *1* of *2*

# CONTROL VALVE SPECIFICATION

| | | | |
|---|---|---|---|
| Item | | | |
| Quantity | | | *2* |
| Application | | | *Pressure Regulating* |
| Tag | | | |
| Size and Type | | | *6" ED* |
| Body | Style | | ☐ Angle ☐ Globe ■ |
| Body | End Connections | | ☐ SWE Scrd. ☐ Flg. *300 #* ANSI RF ■ ☐ BWE Sched. ____ Casting Rating ____ ☐ |
| Body | Material | | 316 SST ☐ WCB Steel ■ ☐ Iron ☐ |
| Body | Number of Ports | | Two ☐ One ■ |
| Body | Push Down to | | Open ■ Close ☐ |
| Body | Flow Direction | | Up ■ Down ☐ |
| Trim | Trim Number | | |
| Trim | Cage and/or Bushing Material | | Std. ■ ☐ |
| Trim | Seat Ring Material | | ☐ Std. ■ |
| Trim | Valve Plug | Material | ☐ Std. ■ |
| Trim | Valve Plug | Guiding | Top ☐ Cage ■ Top & Bottom ☐ Port ☐ |
| Trim | Valve Plug | Balance | Unbalanced ☐ Balanced ■ |
| Trim | Port Size | | ■ *REDUCED* Full ☐ |
| Trim | Plug or Cage | | Linear ☐ Q.O. ☐ ☐ Equal Percent. ■ |
| Trim | Shutoff Class | | ☐ Std. ■ |
| Bonnet | Style | | ☐ Ext.# Std. ■ |
| Bonnet | Boss Size | | ☐ Std. ■ |
| Bonnet | Packing | | ☐ Lam. Graphite TFE ■ ☐ Lubr. & Iso. Valve TFE Asb. ☐ ☐ |
| Bonnet | Bolting | Bonnet | ☐ Std. ■ |
| Bonnet | Bolting | Pack. Flg. | ☐ Std. ■ |

Notes and/or Special Constructions

*ED = % @ 1-78 (6" Reduced Port 4 3/8" ∅*
*43% - 100%)*

| | | |
|---|---|---|
| Actuator | Style | ☐ Diaph. ■ Piston ☐ |
| Actuator | Size | *60* |
| Actuator | Air to Actuator | ☐ 6-30 ☐ 3-15 ☐ |
| Actuator | Air Fails Valve to | Lock ☐ Open ■ Close ☐ |
| Actuator | Handjack | ☐ Top ■ Side |
| Positioner | Type | 3570 ☐ 3582 ☐ 3590 ■ |
| Positioner | Input Signal | ☐ 4-20 mA ■ 10-50 mA ☐ ☐ 6-30 psi ☐ 3-15 psi ☐ |
| Positioner | Output Signal (Psi) | ☐ 6-30 ☐ 3-15 ■ |
| Positioner | Accessories | Bypass ☐ Gauges ☐ Airset ■ |
| Positioner | Increase Signal Valve | Opens ☐ Closes ■ |
| Wizard Pilot | Type | |
| Wizard Pilot | Action | Reverse ☐ Direct ☐ |
| Wizard Pilot | Measuring Element | Bourdon Tube ☐ Bronze ☐ Bellows ☐ Steel ☐ Range ____ Psig SST ☐ |
| Wizard Pilot | Output (Psig) | ☐ 6-30 ☐ 3-15 ☐ |
| Wizard Pilot | Mounting | Remote ☐ Csg. ☐ Yoke ☐ |
| Wizard Pilot | Airset | ☐ 67FR-221 ☐ |
| Wizard Pilot | Airset Mounting | Nipple ☐ Yoke ☐ |
| 546 | Input Signal (mA) | ☐ 4-20 ☐ 10-50 ☐ |
| 546 | Output Signal (Psig) | ☐ 6-30 ☐ 3-15 ☐ |
| 546 | Action | Reverse ☐ Direct ☐ |
| 546 | Mounting | Pipe ☐ Csg. ☐ Yoke ☐ |
| 546 | Airset W/Gauge | ☐ 67FR-362 ☐ |

Service Conditions

Throttling ■ On-Off ☐ PVR ■ Relief ☐

| Flowing Media | *Sat. Steam @ 100 psig* | | |
|---|---|---|---|
| | Minimum | Normal | Maximum |
| Specific Gravity | *0.25* | | *0.25* |
| Inlet Temperature *Saturated* | | | |
| Inlet Pressure (Psig) | *100* | *100* | *100* |
| Inlet Vapor Pressure | | | |
| ΔP Sizing (Psi) | *70* | | *20* |
| ΔP Shutoff (Psi) | *—* | *—* | *125* |
| Flow Rate, Give Units *lbs/hr* | *6000* | | *40,000* |
| Req'd Flow Coeff., $C_v$ ☐ $C_g$ ☐ $C_s$ ■ | *54* | | *460* |
| Valve Coefficient | *33 or 35* | | |
| Recovery Coeff., $K_m$ ☐ $C_1$ ☐ | *36.1* | | |
| Noise Level (dBA) | | | |
| Line Size (In.) | | | |

Worksheet

| Approximate Shipping Weight | List Price | $ |
|---|---|---|
| | Unit Net Price | $ |
| | Total Net Price | $ |

FISHER Controls

# Fisher Controls Company

M A R S H A L L T O W N , I O W A

## CONTROL VALVE SPECIFICATION

Customer: Fort Benjamin Harrison
Reference:
Order No.
Quote No.
Date ______ Page 2 of 2

| | | | |
|---|---|---|---|
| Item | | | |
| Quantity | | 1 | |
| Application | | Pressure Regulating | |
| Tag | | 6 | |
| Size and Type | | 4" ED | |
| Body | Style | ☐ Angle ☐ Globe ■ | |
| | End Connections | ☐ SWE Scrd. ☐ Flg. 300 # ANSI RF ☐ ☐ BWE Sched. ____ Casting Rating ____ ☐ | |
| | Material | 316 SST ☐ WCB Steel ■ ☐ Iron ☐ | |
| | Number of Ports | Two ☐ One ■ | |
| | Push Down to | Open ■ Close ☐ | |
| | Flow Direction | Up ■ Down ☐ | |
| Trim | Trim Number | | |
| | Cage and/or Bushing Material | Std. ■ ☐ | |
| | Seat Ring Material | ☐ Std. ■ | |
| | Valve Plug – Material | ☐ Std. ■ | |
| | Valve Plug – Guiding | Top ☐ Cage ■ Top & Bottom ☐ Port ☐ | |
| | Valve Plug – Balance | Unbalanced ☐ Balanced ■ | |
| | Port Size | ☐ Full ■ | |
| | Plug or Cage | Linear ☐ Q.O. ☐ ☐ Equal Percent. ■ | |
| | Shutoff Class | ☐ Std. ■ | |
| Bonnet | Style | ☐ Ext.# Std. ■ | |
| | Boss Size | ☐ Std. ■ | |
| | Packing | ☐ Lam. Graphite TFE ■ ☐ Lubr. & Iso. Valve TFE Asb. ☐ ☐ | |
| | Bolting – Bonnet | ☐ Std. ■ | |
| | Bolting – Pack. Flg. | ☐ Std. ■ | |

| | | |
|---|---|---|
| Actuator | Style | ☐ Diaph. ■ Piston ☐ |
| | Size | 40 |
| | Air to Actuator | ☐ 6-30 ☐ 3-15 ☐ |
| | Air Fails Valve to | Lock ☐ Open ■ Close ☐ |
| | Handjack | ☐ Top ■ Side |
| Positioner | Type | 3570 ☐ 3582 ☐ 3590 ■ |
| | Input Signal | ☐ 4-20 mA ■ 10-50 mA ☐ ☐ 6-30 psi ☐ 3-15 psi ☐ |
| | Output Signal (Psi) | ☐ 6-30 ☐ 3-15 ■ |
| | Accessories | Bypass ☐ Gauges ☐ Airset ■ |
| | Increase Signal Valve | Opens ☐ Closes ■ |
| Wizard Pilot | Type | |
| | Action | Reverse ☐ Direct ☐ |
| | Measuring Element | Bourdon Tube ☐ Bronze ☐ Bellows ☐ Steel ☐ Range. ____ Psig SST ☐ |
| | Output (Psig) | ☐ 6-30 ☐ 3-15 ☐ |
| | Mounting | Remote ☐ Csg. ☐ Yoke ☐ |
| | Airset | ☐ 67FR-221 ☐ |
| | Airset Mounting | Nipple ☐ Yoke ☐ |
| 546 | Input Signal (mA) | ☐ 4-20 ☐ 10-50 ☐ |
| | Output Signal (Psig) | ☐ 6-30 ☐ 3-15 ☐ |
| | Action | Reverse ☐ Direct ☐ |
| | Mounting | Pipe ☐ Csg. ☐ Yoke ☐ |
| | Airset W/Gauge | ☐ 67FR-362 ☐ |

**Service Conditions**

Throttling ■ On-Off ☐ PVR ■ Relief ☐

| Flowing Media | Sat. Steam @ 100 psig | | |
|---|---|---|---|
| | Minimum | Normal | Maximum |
| Specific Gravity | .25 | | .25 |
| Inlet Temperature Saturated | | | |
| Inlet Pressure (Psig) | 100 | 100 | 100 |
| Inlet Vapor Pressure | | | |
| ΔP Sizing (Psi) | 70 | | 20 |
| ΔP Shutoff (Psi) | 100 | | 125 |
| Flow Rate, Give Units lbs/hr | 4000 | | 30000 |
| Req'd Flow Coeff., $C_v$ ☐ $C_g$ ☐ $C_s$ ■ | 31 | | 350 |
| Valve Coefficient | 33 or 35 | | |
| Recovery Coeff., $K_m$ ☐ $C_1$ ☐ | | | |
| Noise Level (dBA) | | | |
| Line Size (In.) | | | |

**Worksheet**

| Approximate | List Price | $ |
|---|---|---|
| Shipping Weight, | Unit Net Price | $ |
| lb | Total Net Price | $ |

Notes and/or Special Constructions

ED = % @ 1-78 (4" Full 31%-95%)

FORT HARRISON
FLOW METER PARAMETERS

| | ALPHA VALUE | BETA VALUE | DELTA VALUE |
|---|---|---|---|
| SERIAL # | 5316102 | 5316164 | 5316163 |
| TEMPERATURE (DEG F) | 337.6 | 337.6 | 337.6 |
| PRESSURE (PSIA) | 114.3 | 114.3 | 114.3 |
| SPECIFIC GRAVITY | 0.6220236 | 0.6220236 | 0.6220236 |
| COMPRESSIBILITY (ZF) | 0.9395093 | 0.9395093 | 0.9395093 |
| VISCOSITY (CENTIPOISES) | 0.0147 | 0.0147 | 0.0147 |
| DENSITY (LBM./CU.FT.) | 0.2561655 | 0.2561655 | 0.2561655 |

| PARAM. N | MNEM. | ALPHA VALUE | BETA VALUE | DELTA VALUE |
|---|---|---|---|---|
| 1 | REVN | 2-10-1 | 2-10-1 | 2-10-1 |
| 2 | HSS | 200010 | 200010 | 200010 |
| 3 | SSS | 20000 | 20000 | 20000 |
| 4 | MPS | 316161 | 316161 | 316161 |
| 5 | FIS | 10000 | 10000 | 10000 |
| 6 | SCODE | 0 | 0 | 0 |
| 7 | INVT | 0 | 0 | 0 |
| 8 | PSDT | 0 | 0 | 0 |
| 9 | KF | 0 | 0 | 0 |
| 10 | VHMAX | 100 | 100 | 100 |
| 11 | ALMHI | 100 | 100 | 100 |
| 12 | ALMLO | 0 | 0 | 0 |
| 13 | OMIN | 0 | 0 | 0 |
| 14 | TRAMP | 0 | 0 | 0 |
| 15 | TMAX | 797.27 | 797.27 | 797.27 |
| 16 | TMIN | 797.27 | 797.27 | 797.27 |
| 17 | TREF | 0 | 0 | 0 |
| 18 | DTMAX | 0 | 0 | 0 |
| 19 | DTMIN | 0 | 0 | 0 |
| 20 | PMAX | 114.3 | 114.3 | 114.3 |
| 21 | PMIN | 114.3 | 114.3 | 114.3 |
| 22 | PREF | 0 | 0 | 0 |
| 23 | GDMAX | 0.2561655 | 0.2561655 | 0.2561655 |
| 24 | GDMIN | 0.2561655 | 0.2561655 | 0.2561655 |
| 25 | DO | 5.6239 | 5.8382 | 5.1876 |
| 26 | OP | 7.981 | 10.02 | 11.938 |
| 27 | YK | 0.4962957 | 0.4503379 | 0.4224798 |

| | | | | |
|---|---|---|---|---|
| 28 | RK0 | 0.69341 | 0.6421313 | 0.6121461 |
| 29 | RK1 | 44.03954 | 25.26589 | 11.62487 |
| 30 | APE | 9.500001 | 9.500001 | 9.500001 |
| 31 | AIN | 50 | 50 | 50 |
| 32 | AOUT | 50 | 50 | 50 |
| 33 | BIN | 50 | 50 | 50 |
| 34 | BOUT | 50 | 50 | 50 |
| 35 | KZ | 0.974514 | 0.974514 | 0.974514 |
| 36 | TC | 1165.14 | 1165.14 | 1165.14 |
| 37 | PC | 3208.24 | 3208.24 | 3208.24 |
| 38 | KC | 1.3 | 1.3 | 1.3 |
| 39 | MCP | 0.0147 | 0.0147 | 0.0147 |
| 40 | CL | 0 | 0 | 0 |
| 41 | RS | 0 | 0 | 0 |
| 42 | FMAX | 39.88622 | 39.88622 | 29.94338 |
| 43 | CFMAX | 150000 | 150000 | 150000 |
| 44 | CFMIN | 31000 | 31000 | 31000 |
| 45 | C1MAX | 0 | 0 | 0 |
| 46 | C1MIN | 0 | 0 | 0 |
| 47 | C2MAX | 0 | 0 | 0 |
| 48 | C2MIN | 0 | 0 | 0 |
| 49 | C3MAX | 0 | 0 | 0 |
| 50 | C3MIN | 0 | 0 | 0 |
| 51 | CVMAX | 0 | 0 | 0 |
| 52 | CVMIN | 0 | 0 | 0 |
| 53 | CAMAX | 1250 | 1325 | 1800 |
| 54 | CAMIN | 6200 | 6200 | 6500 |
| | INPUT 80%: DISPLAY | 35.3 | 35.3 | 26.7 |
| | INPUT 40%: DISPLAY | 25.2 | 25.2 | 19 |

Controller Parameters

| Controller | | Alpha | Beta | Delta |
|---|---|---|---|---|
| SECURE ALLTUNE | | | | |
| MODES P | | | | |
| | PF | 75.00 | 232.00 | 183.00 |
| | IF | 0.76 | 2.60 | 3.60 |
| | DF | 0.00 | 0.43 | 0.39 |
| | EXACT STATE | ON | ON | ON |
| | NB | 2.00 | 1.00 | 1.40 |
| | WMAX | 3.00 | 8.67 | 12.00 |
| | DMP | 0.30 | 0.30 | 0.30 |
| | OVR | 0.50 | 0.50 | 0.50 |
| | CLM | 4.00 | 4.00 | 4.00 |
| | DFCT | 0.00 | 0.00 | 0.00 |
| | LIM | 80.00 | 80.00 | 80.00 |
| | BUMP | 8.00 | 8.00 | 8.00 |
| SETLIMP | | | | |
| | HIGH | 100 | 100 | 100 |
| | LOW | 25 | 30 | 30 |
| SETLIMS | | | | |
| | HIGH | 0 | 0 | 0 |
| | LOW | 0 | 0 | 0 |
| OUTLIMS | | | | |
| | HIGH | 0 | 0 | 0 |
| | LOW | 0 | 0 | 0 |
| ALARMS | | | | |
| ALARM1 | LEVEL1 | 25 | 30 | 30 |
| | LEVEL2 | 25 | 30 | 30 |
| | DB | 2 | 2 | 2 |
| CONFIG CTLR | | | | |
| CTRL PRIMARY | | | | |
| | TAG DISP | ALPHA 1 | BETA 400 | DELTA 300 |
| | SEL DISP TYPE | LIN | LIN | LIN |
| | ENG UNITS | PSI | PSI | PSI |
| | SCALING URV | 100 | 100 | 100 |
| | LRV | 0 | 0 | 0 |
| | ALARMS MEAS | ALARM1 | ALARM1 | ALARM1 |
| | OUT | NONE | NONE | NONE |
| | MET REV | YES | YES | YES |
| PRIMARY RATIO | | OFF | OFF | OFF |

| | | | | |
|---|---|---|---|---|
| PRIMARY SET POINT | | | | |
| | TYPE | R/L | R/L | R/L |
| | INBIAS | 0 | 0 | 0 |
| | LOCTRK | NONE | NONE | NONE |
| | SOURCE | D | B | B |
| | SWITCH | NONE | NONE | NONE |
| | STARTUP | L | L | L |
| | MEAS TRK | NONE | NONE | NONE |
| | FORMAT | LIN | LIN | LIN |
| PRIMARY MEAS | | | | |
| | FORMAT | LIN | LIN | LIN |
| | SOURCE | A | A | A |
| PRIMARY A/M | | | | |
| | STARTUP | M | M | M |
| | FLUNK | M | M | M |
| | SWITCH | NONE | NONE | NONE |
| PRIMARY NONLIN | | NO | NO | NO |
| PRIMARY ACTION | | INC/INC | INC/INC | INC/INC |
| PRIMARY TYPE | | EXACT | EXACT | EXACT |
| (EXACT) | | NONE | NONE | NONE |
| PRIMARY OUTPUT | | | | |
| | FORMAT | LIN | LIN | LIN |
| | MODIFIER | NO | NO | NO |
| OUTTRK | | | | |
| | SWITCH | NONE | NONE | NONE |
| | EXTLIM | NONE | NONE | NONE |
| | STARTUP | LAST VAL | LAST VAL | LAST VAL |
| PRIMARY BATCH | | OFF | OFF | OFF |
| PRIMARY EXTRES | | OUT P | OUT P | OUT P |
| CTLR SECONDRY | | | | |
| | TAG DISP | LOC.PRESS | | AMB.TEMP. |
| SEL DISP | | | | |
| | TYPE | LIN | | LIN |
| | ENG UNITS | PSI | | DEG.F |
| SCALING | URV | 100 | | 100 |
| | LRV | 0 | | -20 |
| ALARMS | MEAS | NONE | | NONE |
| | OUT | NONE | | NONE |
| | MET REV | NO | | NO |

| | | | | |
|---|---|---|---|---|
| SECONDARY RATIO | | OFF | | OFF |
| SECONDARY MEAS | | NONE | NONE | IN2 |
| CONFIG INPUTS | | | | |
| INPUTS A | | | | |
| | OUTBIAS | 0 | 0 | 0 |
| | GAIN | 1 | 1 | 1 |
| | INBIAS | 0 | 0 | 0 |
| | FORMAT | LIN | LIN | LIN |
| | FILTER | 0 | 0 | 0 |
| INPUTS B | | | | |
| | OUTBIAS | 0 | 0 | 0 |
| | GAIN | 1 | 1 | 1 |
| | INBIAS | 0 | 0 | 0 |
| | FORMAT | LIN | CHAR 1 | CHAR 1 |
| | FILTER | 0 | 0 | 0 |
| INPUTS C | | | | |
| | OUTBIAS | 0 | 0 | 0 |
| | GAIN | 1 | 1 | 1 |
| | INBIAS | 0 | 0 | 0 |
| | FORMAT | LIN | LIN | LIN |
| | FILTER | 0 | 0 | 0 |
| INPUTS D | | | | |
| | OUTBIAS | 0 | 0 | 0 |
| | GAIN | 1 | 1 | 1 |
| | INBIAS | 0 | 0 | 0 |
| | FORMAT | CHAR 1 | LIN | LIN |
| | FILTER | 0 | 0 | 0 |
| CONFIG ALARMS | | | | |
| ALARM 1 | | | | |
| | TYPE | LO/LO | LO/LO | LO/LO |
| | ACTION | NON LAT | NON LAT | NON LAT |
| | FORM | ABS | ABS | ABS |
| | ATTACH | MEAS P | MEAS P | MEAS P |
| ALARM 2 | TYPE | NO | NO | NO |
| ALARM 3 | TYPE | NO | NO | NO |
| ALARM 4 | TYPE | NO | NO | NO |
| ALARMS EXT ACK | | NONE | NONE | NONE |

| | | | |
|---|---|---|---|
| CONFIG CALC | | | |
| CALC CHAR 1 | | | |
| POINTS | 16 | 16 | 16 |
| X1..X16 | TABLE 7 | TABLE 7 | TABLE 7 |
| Y1..Y16 | TABLE 7 | TABLE 7 | TABLE 7 |
| CONFIG CASCADE | YES | NO | YES |
| (YES) | OFF | OFF | OFF |
| CONFIG W/P | OFF | OFF | OFF |
| CONFIG NEW PASS | ACK ACK ACK | ACK ACK ACK | ACK ACK ACK |
| CONFIG TOGGLE | OFF | OFF | OFF |
| CONFIG PH DISPLAY | OFF | OFF | OFF |
| CONFIG OUT 2 | IN4 | IN2 | IN2 |
| CONFIG CO O/PS | | | |
| CO 1 | NONE | NONE | NONE |
| CO 2 | NONE | NONE | NONE |

**Fort Harrison Controller Set Points**
**Temperature vs. Steam Pressure**

| Temp, X (% of Signal) | | Actual Temp | Alpha Steam Pressure, Y Alpha | | Beta Steam Pressure, Y Beta | Delta Steam Pressure, Y Delta |
|---|---|---|---|---|---|---|
| X01 | 0 | -20.0 | Y01 | 100 | 100 | 100 |
| X02 | 16.7 | 0.0 | Y02 | 75 | 80 | 100 |
| X03 | 18.8 | 2.6 | Y03 | 68 | 77 | 99 |
| X04 | 20.8 | 5.0 | Y04 | 64 | 75 | 99 |
| X05 | 22.9 | 7.5 | Y05 | 61 | 73 | 99 |
| X06 | 25 | 10.0 | Y06 | 58 | 70 | 98 |
| X07 | 27.1 | 12.5 | Y07 | 56 | 68 | 96 |
| X08 | 33.3 | 15.0 | Y08 | 54 | 64 | 93 |
| X09 | 37.5 | 20.0 | Y09 | 50 | 60 | 90 |
| X10 | 41.7 | 25.0 | Y10 | 46 | 56 | 87 |
| X11 | 50 | 30.0 | Y11 | 43 | 55 | 83 |
| X12 | 45.8 | 35.0 | Y12 | 40 | 55 | 81 |
| X13 | 50 | 40.0 | Y13 | 38 | 55 | 78 |
| X14 | 58.3 | 50.0 | Y14 | 35 | 55 | 73 |
| X15 | 66.7 | 60.0 | Y15 | 35 | 55 | 70 |
| X16 | 100 | 100.0 | Y16 | 35 | 55 | 70 |

## APPENDIX D: Daily Operating Data for April 1991

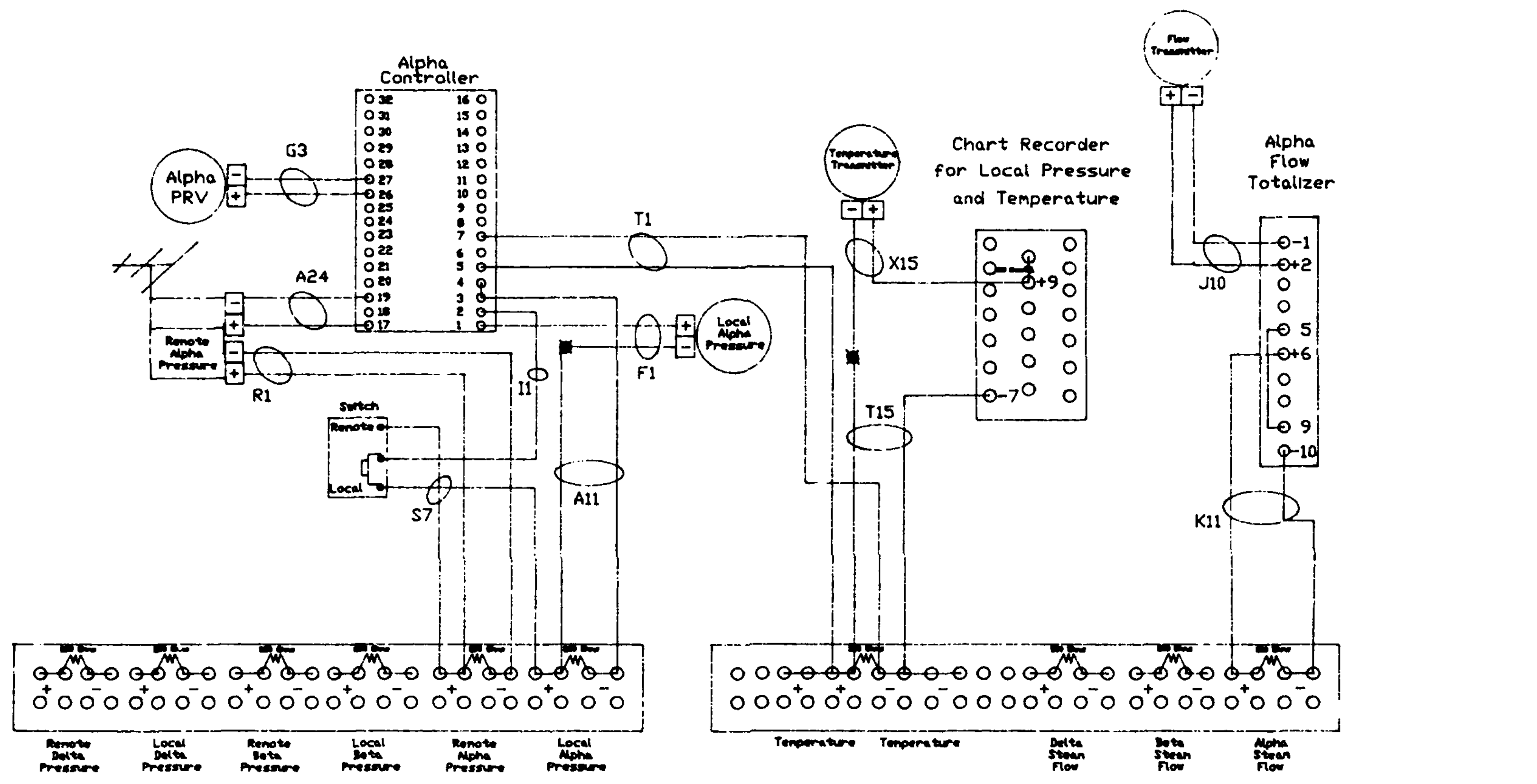
This appendix includes the April 1991 daily database file. This month's file is characteristic of the majority of the other files, showing many of the situations that arose during the demonstration that needed to be addressed.

In April 1991, four different events require comment. From April 1-4, the SDCS was working and the data gathered was considered "winter load data with SDCS." On April 5, all three line pressure reducing valves were fully opened, and on April 20 SDCS was placed back into operation; both events were planned. The data taken on April 5 and April 20 were considered mixed data, and were not used. Also, on April 5, the plant totalizer for the total steam flow was recalibrated. None of the data taken after April 5 could be compared with the data taken previously. However, only 2.5 weeks of winter load data were lost due to the recalibration. Data from April 6-19 would have been put into the baseline winter load data. Likewise, the data from April 21-23 would have been considered winter load data with SDCS. On April 24 the steam line feeding the Series 600 buildings was closed. This marked the start of the summer load data. All of the April data after the 24th was considered "summer load data with SDCS working."

The remote Beta pressure instrumentation was not working correctly during this period, however, due to equipment failure. Also, the Delta flow totalizer was rewired to record the Alpha steam flow. This was done as a check on the Alpha totalizer, which had just been repaired.

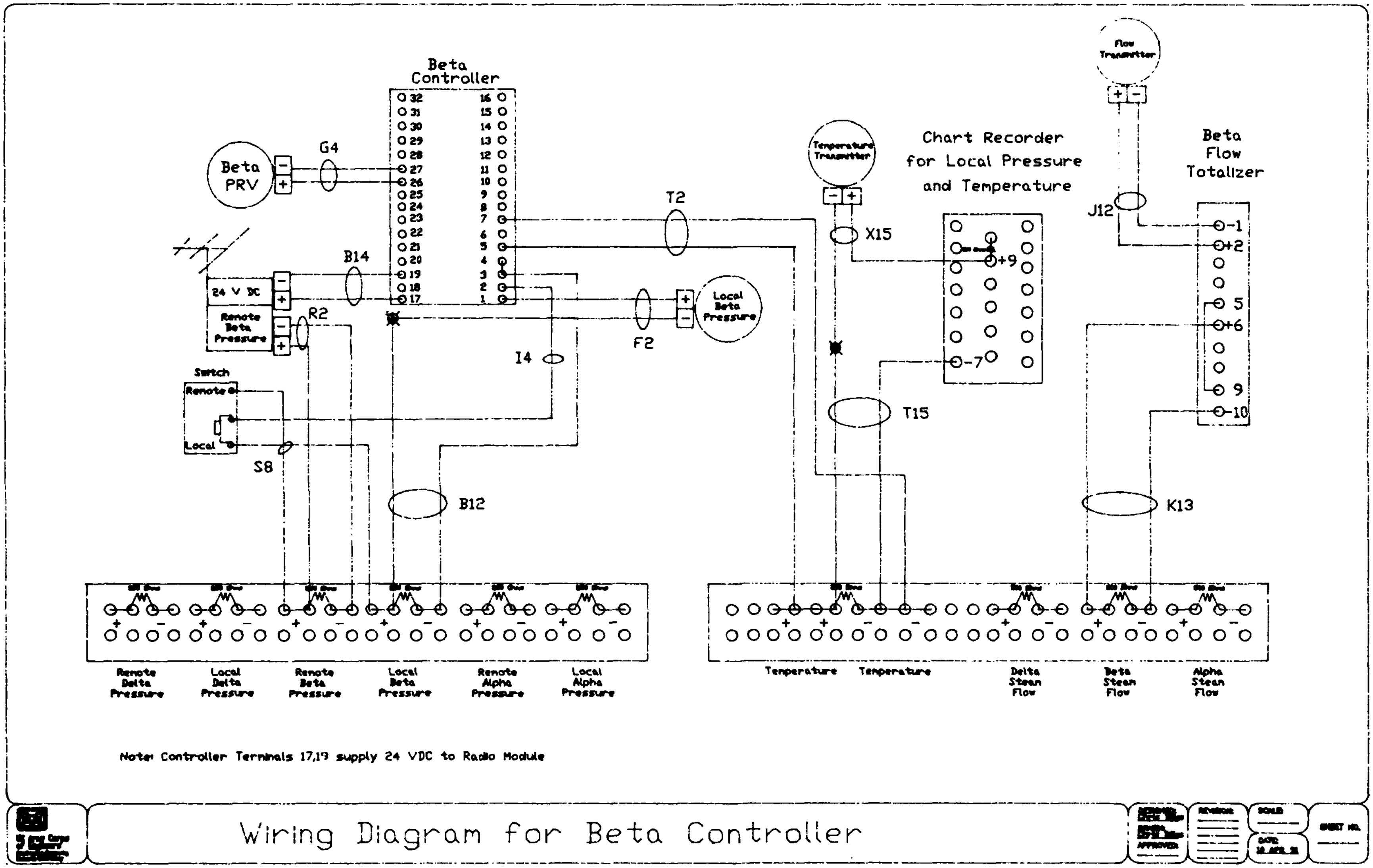
| Date | Alpha Local Pressure (psig) | Beta Local Pressure (psig) | Delta Local Pressure (psig) | Temp (deg F) | Alpha Remote Pressure (psig) | Beta Remote Pressure (psig) | Delta Remote Pressure (psig) | Alpha Steam Flow (lbs/hr) | Beta Steam Flow (lbs/hr) | Delta Steam Flow (lbs/hr) | Total Steam Flow (1000 lbs) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 04/01/91 | 36.2 | 55.3 | 75.9 | 44.9 | 35.2 | -0.7 | 67.6 | 1177.5 | 14959.7 | 1176.2 | 983 |
| 04/02/91 | 37.6 | 55.2 | 75.9 | 41.7 | 36.6 | -0.7 | 67.6 | 1047.5 | 14831.4 | 1041.6 | 889 |
| 04/03/91 | 33.7 | 55.1 | 72.9 | 52.1 | 32.9 | -0.7 | 64.6 | 1049.3 | 13893.4 | 1053.7 | 713 |
| 04/04/91 | 32.5 | 55.3 | 71.9 | 53.9 | 31.6 | -0.7 | 63.6 | 972.7 | 13615.1 | 957.7 | 770 |
| 04/05/91 | 60.9 | 71.6 | 62.1 | 62.0 | 59.7 | -0.7 | 53.9 | 774.8 | 13224.3 | 772.3 | 544 |
| 04/06/91 | 94.5 | 94.2 | 94.6 | 66.7 | 93.2 | -0.7 | 86.1 | 356.7 | 12414.7 | 356.7 | 570 |
| 04/07/91 | 94.6 | 94.4 | 95.2 | 69.4 | 93.0 | -0.7 | 86.6 | 372.3 | 12182.6 | 378.0 | 558 |
| 04/08/91 | 94.7 | 94.5 | 95.8 | 64.4 | 93.3 | -0.7 | 87.4 | 381.3 | 12121.3 | 375.5 | 567 |
| 04/09/91 | 94.2 | 94.1 | 94.9 | 59.3 | 93.2 | -0.7 | 86.5 | 1103.2 | 12303.5 | 1103.1 | 669 |
| 04/10/91 | 93.3 | 92.4 | 90.3 | 43.6 | 92.0 | -0.7 | 82.4 | 472.0 | 14248.0 | 463.8 | 843 |
| 04/11/91 | 93.2 | 92.1 | 90.1 | 44.9 | 91.7 | -0.7 | 82.2 | 412.1 | 14554.1 | 414.5 | 831 |
| 04/12/91 | 93.2 | 92.3 | 90.6 | 48.7 | 91.7 | -0.8 | 82.6 | 373.0 | 14319.8 | 367.1 | 771 |
| 04/13/91 | 94.0 | 93.4 | 93.7 | 58.6 | 92.4 | -0.7 | 85.4 | 400.8 | 13751.4 | 402.4 | 665 |
| 04/14/91 | 94.4 | 94.1 | 90.5 | 64.6 | 92.8 | -0.7 | 82.2 | 392.2 | 12642.4 | 396.3 | 613 |
| 04/15/91 | 94.2 | 93.9 | 94.3 | 59.3 | 92.9 | -0.7 | 86.2 | 389.9 | 12829.3 | 390.6 | 648 |
| 04/16/91 | 94.7 | 94.4 | 95.5 | 64.4 | 93.4 | -0.7 | 87.4 | 395.0 | 12416.5 | 398.9 | 526 |
| 04/17/91 | 94.7 | 94.4 | 95.3 | 58.8 | 93.3 | -0.7 | 87.2 | 387.4 | 12348.1 | 391.8 | 590 |
| 04/18/91 | 94.6 | 94.4 | 95.1 | 55.0 | 93.6 | -0.7 | 87.1 | 445.6 | 12301.4 | 448.9 | 559 |
| 04/19/91 | 94.1 | 93.3 | 92.4 | 45.6 | 93.0 | -0.7 | 84.4 | 347.7 | 13760.1 | 349.3 | 734 |
| 04/20/91 | 44.2 | 60.9 | 77.9 | 44.7 | 42.8 | -0.7 | 69.9 | 789.3 | 13318.9 | 789.0 | 732 |
| 04/21/91 | 36.9 | 55.3 | 76.3 | 43.2 | 35.4 | -0.7 | 68.4 | 387.3 | 13664.6 | 382.9 | 801 |
| 04/22/91 | 34.3 | 55.3 | 73.9 | 49.7 | 33.1 | -0.7 | 47.1 | 792.7 | 13155.6 | 795.8 | 635 |
| 04/23/91 | 33.6 | 55.2 | 72.3 | 51.6 | 32.5 | -0.7 | 64.2 | 3079.5 | 12973.4 | 3070.8 | 755 |
| 04/24/91 | 33.7 | 55.3 | 73.2 | 51.0 | 32.8 | -0.7 | 64.7 | 1142.6 | 11225.7 | 1158.9 | 532 |
| 04/25/91 | 32.3 | 55.3 | 71.9 | 54.7 | 31.6 | -0.7 | 61.9 | 646.8 | 10465.4 | 642.3 | 388 |
| 04/26/91 | 30.7 | 54.5 | 70.5 | 64.9 | 30.1 | -0.7 | 61.9 | 766.5 | 10304.0 | 775.3 | 595 |
| 04/27/91 | 30.1 | 54.7 | 70.0 | 65.4 | 29.5 | -0.7 | 62.0 | 815.0 | 10132.6 | 814.9 | 588 |
| 04/28/91 | 30.2 | 54.9 | 70.0 | 63.9 | 29.6 | -0.7 | 61.9 | 773.4 | 10070.7 | 770.7 | 595 |
| 04/29/91 | 30.1 | 54.4 | 70.0 | 67.9 | 29.5 | -0.7 | 62.0 | 705.7 | 9946.7 | 706.5 | 563 |
| 04/30/91 | 30.2 | 54.6 | 70.0 | 66.1 | 29.5 | -0.7 | 62.0 | 670.8 | 9970.9 | 671.3 | 568 |

## APPENDIX E: Circuit Drawings

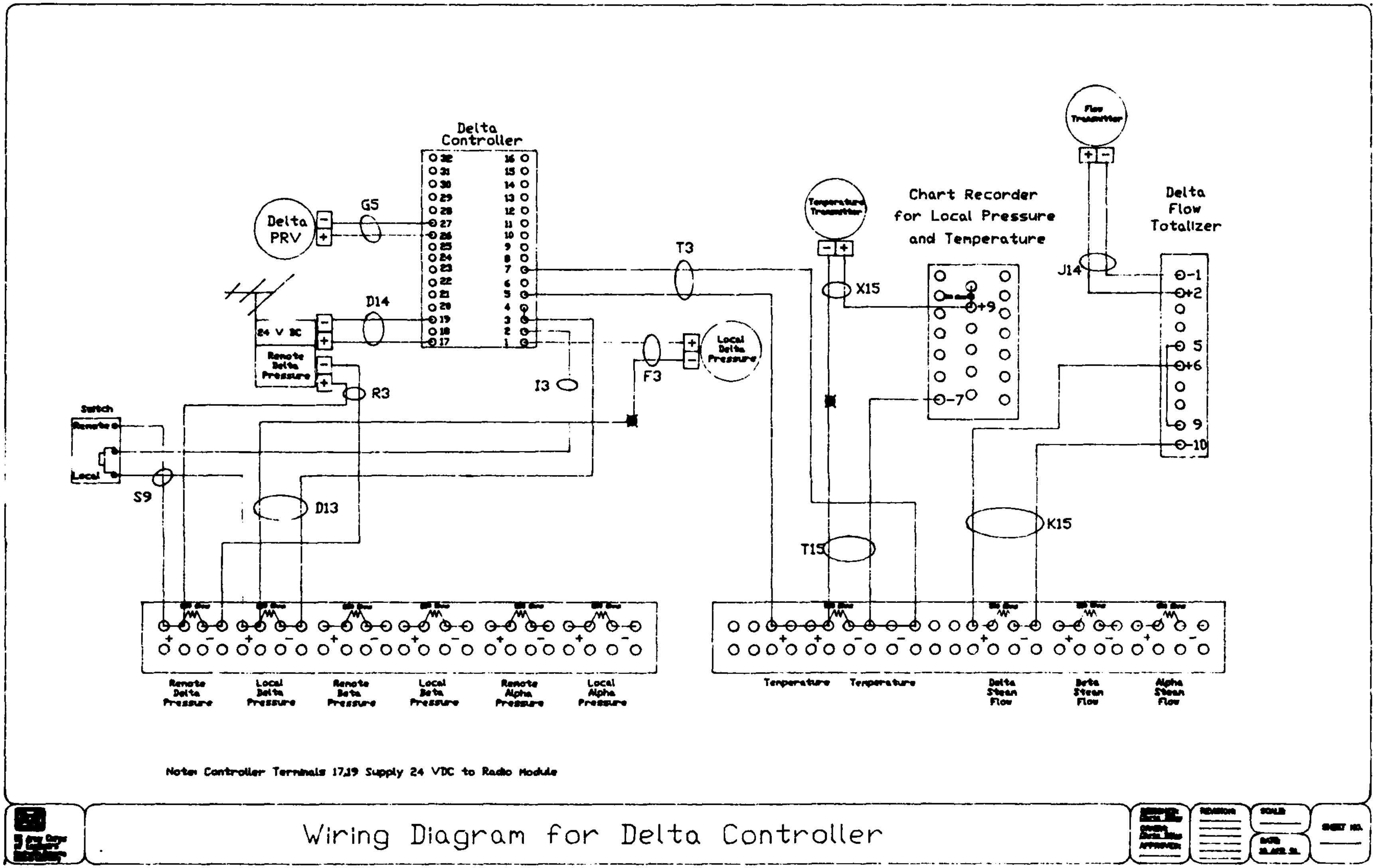



Note: Controller Terminals 17,19 supply 24 VDC to Radio Module

Wiring Diagram for Alpha Controller




Wiring Diagram for Beta Controller



Delta Controller
Delta PRV
G5
D14
24 V DC
Remote Delta Pressure
R3
Switch
Remote
Local
S9
D13
I3
T3
F3
Local Delta Pressure
Temperature Transmitter
X15
Chart Recorder for Local Pressure and Temperature
+9
-7
Flow Transmitter
J14
Delta Flow Totalizer
-1
+2
5
+6
9
-10
K15
T15
Remote Delta Pressure
Local Delta Pressure
Remote Beta Pressure
Local Beta Pressure
Remote Alpha Pressure
Local Alpha Pressure
Temperature
Temperature
Delta Steam Flow
Beta Steam Flow
Alpha Steam Flow
Note: Controller Terminals 17,19 Supply 24 VDC to Radio Module
Wiring Diagram for Delta Controller

## APPENDIX F: ETAC Weather Data

Climate data for the Indianapolis Airport were obtained from the U.S. Air Force Environmental Technical Applications Center (ETAC). These data consisted of the mean maximum and minimum daily temperatures during the period of 1948 to 1989. The mean average daily temperature was calculated as the average of the maximum and minimum temperature for each particular day. A complete listing of the data follows.

Mean Temperatures
for Ft. Benjamin Harrison, IN

| Date | Maximum Temp | Minimum Temp | Average Temp |
|---|---|---|---|
| 01-Jan | 37 | 21 | 29.0 |
| 02-Jan | 36 | 22 | 29.0 |
| 03-Jan | 37 | 22 | 29.5 |
| 04-Jan | 35 | 19 | 27.0 |
| 05-Jan | 34 | 19 | 26.5 |
| 06-Jan | 35 | 20 | 27.5 |
| 07-Jan | 34 | 18 | 26.0 |
| 08-Jan | 33 | 16 | 24.5 |
| 09-Jan | 34 | 17 | 25.5 |
| 10-Jan | 33 | 17 | 25.0 |
| 11-Jan | 33 | 16 | 24.5 |
| 12-Jan | 34 | 17 | 25.5 |
| 13-Jan | 37 | 19 | 28.0 |
| 14-Jan | 35 | 20 | 27.5 |
| 15-Jan | 34 | 17 | 25.5 |
| 16-Jan | 32 | 15 | 23.5 |
| 17-Jan | 33 | 18 | 25.5 |
| 18-Jan | 36 | 19 | 27.5 |
| 19-Jan | 36 | 19 | 27.5 |
| 20-Jan | 34 | 19 | 26.5 |
| 21-Jan | 35 | 19 | 27.0 |
| 22-Jan | 36 | 21 | 28.5 |
| 23-Jan | 36 | 19 | 27.5 |
| 24-Jan | 37 | 20 | 28.5 |
| 25-Jan | 37 | 20 | 28.5 |
| 26-Jan | 35 | 17 | 26.0 |
| 27-Jan | 32 | 17 | 24.5 |
| 28-Jan | 33 | 15 | 24.0 |
| 29-Jan | 33 | 16 | 24.5 |
| 30-Jan | 33 | 16 | 24.5 |
| 31-Jan | 34 | 17 | 25.5 |
| 01-Feb | 36 | 20 | 28.0 |
| 02-Feb | 35 | 17 | 26.0 |
| 03-Feb | 33 | 18 | 25.5 |
| 04-Feb | 35 | 17 | 26.0 |
| 05-Feb | 37 | 19 | 28.0 |
| 06-Feb | 33 | 19 | 26.0 |
| 07-Feb | 33 | 16 | 24.5 |
| 08-Feb | 34 | 17 | 25.5 |
| 09-Feb | 36 | 18 | 27.0 |
| 10-Feb | 38 | 19 | 28.5 |

| Date | Maximum Temp | Minimum Temp | Average Temp |
|---|---|---|---|
| 11-Feb | 36 | 20 | 28.0 |
| 12-Feb | 37 | 20 | 28.5 |
| 13-Feb | 39 | 22 | 30.5 |
| 14-Feb | 40 | 23 | 31.5 |
| 15-Feb | 40 | 23 | 31.5 |
| 16-Feb | 39 | 23 | 31.0 |
| 17-Feb | 40 | 23 | 31.5 |
| 18-Feb | 44 | 25 | 34.5 |
| 19-Feb | 41 | 25 | 33.0 |
| 20-Feb | 42 | 23 | 32.5 |
| 21-Feb | 41 | 24 | 32.5 |
| 22-Feb | 43 | 24 | 33.5 |
| 23-Feb | 44 | 26 | 35.0 |
| 24-Feb | 43 | 26 | 34.5 |
| 25-Feb | 42 | 25 | 33.5 |
| 26-Feb | 42 | 23 | 32.5 |
| 27-Feb | 43 | 24 | 33.5 |
| 28-Feb | 44 | 27 | 35.5 |
| 01-Mar | 44 | 25 | 34.5 |
| 02-Mar | 45 | 27 | 36.0 |
| 03-Mar | 47 | 29 | 38.0 |
| 04-Mar | 47 | 29 | 38.0 |
| 05-Mar | 45 | 28 | 36.5 |
| 06-Mar | 46 | 28 | 37.0 |
| 07-Mar | 45 | 28 | 36.5 |
| 08-Mar | 47 | 26 | 36.5 |
| 09-Mar | 47 | 27 | 37.0 |
| 10-Mar | 46 | 29 | 37.5 |
| 11-Mar | 48 | 30 | 39.0 |
| 12-Mar | 47 | 31 | 39.0 |
| 13-Mar | 48 | 30 | 39.0 |
| 14-Mar | 48 | 31 | 39.5 |
| 15-Mar | 48 | 30 | 39.0 |
| 16-Mar | 48 | 30 | 39.0 |
| 17-Mar | 49 | 29 | 39.0 |
| 18-Mar | 50 | 30 | 40.0 |
| 19-Mar | 51 | 33 | 42.0 |
| 20-Mar | 52 | 32 | 42.0 |
| 21-Mar | 51 | 32 | 41.5 |
| 22-Mar | 50 | 31 | 40.5 |
| 23-Mar | 53 | 32 | 42.5 |
| 24-Mar | 52 | 32 | 42.0 |
| 25-Mar | 52 | 33 | 42.5 |
| 26-Mar | 53 | 34 | 43.5 |

| Date | Maximum Temp | Minimum Temp | Average Temp | Date | Maximum Temp | Minimum Temp | Average Temp |
|---|---|---|---|---|---|---|---|
| 27-Mar | 55 | 34 | 44.5 | 10-May | 71 | 49 | 60.0 |
| 28-Mar | 58 | 37 | 47.5 | 11-May | 71 | 52 | 61.5 |
| 29-Mar | 58 | 39 | 48.5 | 12-May | 71 | 52 | 61.5 |
| 30-Mar | 55 | 36 | 45.5 | 13-May | 73 | 50 | 61.5 |
| 31-Mar | 57 | 36 | 46.5 | 14-May | 74 | 53 | 63.5 |
| 01-Apr | 58 | 38 | 48.0 | 15-May | 74 | 52 | 63.0 |
| 02-Apr | 58 | 38 | 48.0 | 16-May | 74 | 52 | 63.0 |
| 03-Apr | 58 | 38 | 48.0 | 17-May | 74 | 52 | 63.0 |
| 04-Apr | 57 | 36 | 46.5 | 18-May | 76 | 52 | 64.0 |
| 05-Apr | 57 | 37 | 47.0 | 19-May | 76 | 53 | 64.5 |
| 06-Apr | 58 | 38 | 48.0 | 20-May | 75 | 54 | 64.5 |
| 07-Apr | 60 | 36 | 48.0 | 21-May | 78 | 54 | 66.0 |
| 08-Apr | 57 | 36 | 46.5 | 22-May | 77 | 55 | 66.0 |
| 09-Apr | 54 | 35 | 44.5 | 23-May | 76 | 54 | 65.0 |
| 10-Apr | 59 | 36 | 47.5 | 24-May | 76 | 54 | 65.0 |
| 11-Apr | 61 | 38 | 49.5 | 25-May | 77 | 54 | 65.5 |
| 12-Apr | 62 | 40 | 51.0 | 26-May | 76 | 54 | 65.0 |
| 13-Apr | 62 | 41 | 51.5 | 27-May | 76 | 55 | 65.5 |
| 14-Apr | 62 | 40 | 51.0 | 28-May | 75 | 55 | 65.0 |
| 15-Apr | 61 | 41 | 51.0 | 29-May | 76 | 55 | 65.5 |
| 16-Apr | 62 | 40 | 51.0 | 30-May | 77 | 56 | 66.5 |
| 17-Apr | 65 | 43 | 54.0 | 31-May | 78 | 56 | 67.0 |
| 18-Apr | 66 | 44 | 55.0 | 01-Jun | 78 | 57 | 67.5 |
| 19-Apr | 66 | 45 | 55.5 | 02-Jun | 78 | 56 | 67.0 |
| 20-Apr | 67 | 45 | 56.0 | 03-Jun | 78 | 56 | 67.0 |
| 21-Apr | 68 | 47 | 57.5 | 04-Jun | 80 | 57 | 68.5 |
| 22-Apr | 68 | 46 | 57.0 | 05-Jun | 81 | 60 | 70.5 |
| 23-Apr | 66 | 47 | 56.5 | 06-Jun | 82 | 60 | 71.0 |
| 24-Apr | 66 | 45 | 55.5 | 07-Jun | 82 | 60 | 71.0 |
| 25-Apr | 68 | 44 | 56.0 | 08-Jun | 82 | 61 | 71.5 |
| 26-Apr | 68 | 46 | 57.0 | 09-Jun | 82 | 61 | 71.5 |
| 27-Apr | 68 | 47 | 57.5 | 10-Jun | 81 | 60 | 70.5 |
| 28-Apr | 66 | 46 | 56.0 | 11-Jun | 82 | 60 | 71.0 |
| 29-Apr | 67 | 45 | 56.0 | 12-Jun | 82 | 61 | 71.5 |
| 30-Apr | 69 | 47 | 58.0 | 13-Jun | 82 | 62 | 72.0 |
| 01-May | 70 | 47 | 58.5 | 14-Jun | 82 | 60 | 71.0 |
| 02-May | 71 | 47 | 59.0 | 15-Jun | 82 | 61 | 71.5 |
| 03-May | 70 | 46 | 58.0 | 16-Jun | 82 | 61 | 71.5 |
| 04-May | 71 | 46 | 58.5 | 17-Jun | 81 | 60 | 70.5 |
| 05-May | 73 | 49 | 61.0 | 18-Jun | 82 | 61 | 71.5 |
| 06-May | 72 | 50 | 61.0 | 19-Jun | 84 | 62 | 73.0 |
| 07-May | 69 | 49 | 59.0 | 20-Jun | 84 | 62 | 73.0 |
| 08-May | 70 | 48 | 59.0 | 21-Jun | 82 | 62 | 72.0 |
| 09-May | 70 | 49 | 59.5 | 22-Jun | 82 | 63 | 72.5 |

| Date | Maximum Temp | Minimum Temp | Average Temp |
|---|---|---|---|
| 23-Jun | 82 | 63 | 72.5 |
| 24-Jun | 84 | 62 | 73.0 |
| 25-Jun | 84 | 62 | 73.0 |
| 26-Jun | 85 | 62 | 73.5 |
| 27-Jun | 85 | 63 | 74.0 |
| 28-Jun | 85 | 64 | 74.5 |
| 29-Jun | 85 | 64 | 74.5 |
| 30-Jun | 86 | 65 | 75.5 |
| 01-Jul | 86 | 64 | 75.0 |
| 02-Jul | 86 | 65 | 75.5 |
| 03-Jul | 85 | 64 | 74.5 |
| 04-Jul | 84 | 64 | 74.0 |
| 05-Jul | 84 | 63 | 73.5 |
| 06-Jul | 85 | 63 | 74.0 |
| 07-Jul | 85 | 64 | 74.5 |
| 08-Jul | 86 | 65 | 75.5 |
| 09-Jul | 85 | 65 | 75.0 |
| 10-Jul | 85 | 65 | 75.0 |
| 11-Jul | 86 | 64 | 75.0 |
| 12-Jul | 86 | 64 | 75.0 |
| 13-Jul | 85 | 65 | 75.0 |
| 14-Jul | 87 | 66 | 76.5 |
| 15-Jul | 86 | 65 | 75.5 |
| 16-Jul | 86 | 65 | 75.5 |
| 17-Jul | 86 | 65 | 75.5 |
| 18-Jul | 86 | 66 | 76.0 |
| 19-Jul | 86 | 67 | 76.5 |
| 20-Jul | 85 | 67 | 76.0 |
| 21-Jul | 86 | 65 | 75.5 |
| 22-Jul | 86 | 67 | 76.5 |
| 23-Jul | 85 | 66 | 75.5 |
| 24-Jul | 85 | 66 | 75.5 |
| 25-Jul | 86 | 66 | 76.0 |
| 26-Jul | 86 | 65 | 75.5 |
| 27-Jul | 86 | 66 | 76.0 |
| 28-Jul | 86 | 66 | 76.0 |
| 29-Jul | 85 | 65 | 75.0 |
| 30-Jul | 85 | 64 | 74.5 |
| 31-Jul | 85 | 65 | 75.0 |
| 01-Aug | 85 | 64 | 74.5 |
| 02-Aug | 84 | 64 | 74.0 |
| 03-Aug | 85 | 64 | 74.5 |
| 04-Aug | 84 | 64 | 74.0 |
| 05-Aug | 84 | 63 | 73.5 |

| Date | Maximum Temp | Minimum Temp | Average Temp |
|---|---|---|---|
| 06-Aug | 84 | 64 | 74.0 |
| 07-Aug | 85 | 64 | 74.5 |
| 08-Aug | 85 | 64 | 74.5 |
| 09-Aug | 84 | 65 | 74.5 |
| 10-Aug | 83 | 64 | 73.5 |
| 11-Aug | 83 | 62 | 72.5 |
| 12-Aug | 83 | 61 | 72.0 |
| 13-Aug | 84 | 62 | 73.0 |
| 14-Aug | 84 | 63 | 73.5 |
| 15-Aug | 84 | 64 | 74.0 |
| 16-Aug | 84 | 64 | 74.0 |
| 17-Aug | 84 | 63 | 73.5 |
| 18-Aug | 85 | 63 | 74.0 |
| 19-Aug | 84 | 63 | 73.5 |
| 20-Aug | 83 | 62 | 72.5 |
| 21-Aug | 83 | 62 | 72.5 |
| 22-Aug | 83 | 61 | 72.0 |
| 23-Aug | 83 | 61 | 72.0 |
| 24-Aug | 83 | 61 | 72.0 |
| 25-Aug | 83 | 61 | 72.0 |
| 26-Aug | 84 | 61 | 72.5 |
| 27-Aug | 84 | 63 | 73.5 |
| 28-Aug | 83 | 63 | 73.0 |
| 29-Aug | 84 | 62 | 73.0 |
| 30-Aug | 84 | 62 | 73.0 |
| 31-Aug | 83 | 62 | 72.5 |
| 01-Sep | 82 | 61 | 71.5 |
| 02-Sep | 82 | 61 | 71.5 |
| 03-Sep | 81 | 61 | 71.0 |
| 04-Sep | 82 | 60 | 71.0 |
| 05-Sep | 82 | 59 | 70.5 |
| 06-Sep | 81 | 57 | 69.0 |
| 07-Sep | 81 | 57 | 69.0 |
| 08-Sep | 81 | 57 | 69.0 |
| 09-Sep | 81 | 57 | 69.0 |
| 10-Sep | 80 | 58 | 69.0 |
| 11-Sep | 79 | 57 | 68.0 |
| 12-Sep | 79 | 56 | 67.5 |
| 13-Sep | 80 | 56 | 68.0 |
| 14-Sep | 78 | 54 | 66.0 |
| 15-Sep | 78 | 55 | 66.5 |
| 16-Sep | 76 | 55 | 65.5 |
| 17-Sep | 78 | 55 | 66.5 |
| 18-Sep | 78 | 56 | 67.0 |

| Date | Maximum Temp | Minimum Temp | Average Temp | Date | Maximum Temp | Minimum Temp | Average Temp |
|---|---|---|---|---|---|---|---|
| 19-Sep | 78 | 56 | 67.0 | 02-Nov | 59 | 40 | 49.5 |
| 20-Sep | 77 | 56 | 66.5 | 03-Nov | 56 | 38 | 47.0 |
| 21-Sep | 76 | 54 | 65.0 | 04-Nov | 55 | 38 | 46.5 |
| 22-Sep | 75 | 53 | 64.0 | 05-Nov | 54 | 36 | 45.0 |
| 23-Sep | 73 | 50 | 61.5 | 06-Nov | 53 | 33 | 43.0 |
| 24-Sep | 73 | 50 | 61.5 | 07-Nov | 54 | 34 | 44.0 |
| 25-Sep | 74 | 51 | 62.5 | 08-Nov | 55 | 36 | 45.5 |
| 26-Sep | 75 | 51 | 63.0 | 09-Nov | 55 | 35 | 45.0 |
| 27-Sep | 73 | 50 | 61.5 | 10-Nov | 53 | 34 | 43.5 |
| 28-Sep | 73 | 50 | 61.5 | 11-Nov | 53 | 34 | 43.5 |
| 29-Sep | 74 | 49 | 61.5 | 12-Nov | 52 | 34 | 43.0 |
| 30-Sep | 73 | 50 | 61.5 | 13-Nov | 54 | 35 | 44.5 |
| 01-Oct | 74 | 49 | 61.5 | 14-Nov | 54 | 34 | 44.0 |
| 02-Oct | 72 | 48 | 60.0 | 15-Nov | 54 | 36 | 45.0 |
| 03-Oct | 71 | 48 | 59.5 | 16-Nov | 55 | 35 | 45.0 |
| 04-Oct | 71 | 48 | 59.5 | 17-Nov | 52 | 35 | 43.5 |
| 05-Oct | 69 | 48 | 58.5 | 18-Nov | 52 | 33 | 42.5 |
| 06-Oct | 68 | 46 | 57.0 | 19-Nov | 50 | 34 | 42.0 |
| 07-Oct | 67 | 45 | 56.0 | 20-Nov | 49 | 32 | 40.5 |
| 08-Oct | 69 | 46 | 57.5 | 21-Nov | 46 | 30 | 38.0 |
| 09-Oct | 68 | 47 | 57.5 | 22-Nov | 47 | 31 | 39.0 |
| 10-Oct | 69 | 45 | 57.0 | 23-Nov | 49 | 29 | 39.0 |
| 11-Oct | 68 | 46 | 57.0 | 24-Nov | 44 | 28 | 36.0 |
| 12-Oct | 68 | 45 | 56.5 | 25-Nov | 47 | 29 | 38.0 |
| 13-Oct | 68 | 45 | 56.5 | 26-Nov | 48 | 32 | 40.0 |
| 14-Oct | 69 | 45 | 57.0 | 27-Nov | 46 | 31 | 38.5 |
| 15-Oct | 69 | 46 | 57.5 | 28-Nov | 42 | 27 | 34.5 |
| 16-Oct | 67 | 45 | 56.0 | 29-Nov | 40 | 26 | 33.0 |
| 17-Oct | 67 | 44 | 55.5 | 30-Nov | 42 | 26 | 34.0 |
| 18-Oct | 64 | 43 | 53.5 | 01-Dec | 43 | 26 | 34.5 |
| 19-Oct | 63 | 41 | 52.0 | 02-Dec | 44 | 28 | 36.0 |
| 20-Oct | 64 | 41 | 52.5 | 03-Dec | 46 | 29 | 37.5 |
| 21-Oct | 65 | 43 | 54.0 | 04-Dec | 44 | 29 | 36.5 |
| 22-Oct | 66 | 43 | 54.5 | 05-Dec | 44 | 29 | 36.5 |
| 23-Oct | 64 | 43 | 53.5 | 06-Dec | 43 | 26 | 34.5 |
| 24-Oct | 60 | 41 | 50.5 | 07-Dec | 43 | 27 | 35.0 |
| 25-Oct | 60 | 39 | 49.5 | 08-Dec | 41 | 26 | 33.5 |
| 26-Oct | 60 | 39 | 49.5 | 09-Dec | 38 | 24 | 31.0 |
| 27-Oct | 62 | 38 | 50.0 | 10-Dec | 37 | 23 | 30.0 |
| 28-Oct | 61 | 39 | 50.0 | 11-Dec | 39 | 24 | 31.5 |
| 29-Oct | 60 | 37 | 48.5 | 12-Dec | 40 | 25 | 32.5 |
| 30-Oct | 62 | 39 | 50.5 | 13-Dec | 37 | 23 | 30.0 |
| 31-Oct | 63 | 43 | 53.0 | 14-Dec | 38 | 24 | 31.0 |
| 01-Nov | 62 | 43 | 52.5 | 15-Dec | 39 | 22 | 30.5 |

| Date | Maximum Temp | Minimum Temp | Average Temp |
|---|---|---|---|
| 16-Dec | 36 | 21 | 28.5 |
| 17-Dec | 37 | 21 | 29.0 |
| 18-Dec | 36 | 20 | 28.0 |
| 19-Dec | 38 | 22 | 30.0 |
| 20-Dec | 38 | 23 | 30.5 |
| 21-Dec | 36 | 22 | 29.0 |
| 22-Dec | 39 | 21 | 30.0 |
| 23-Dec | 39 | 25 | 32.0 |
| 24-Dec | 38 | 22 | 30.0 |
| 25-Dec | 36 | 21 | 28.5 |
| 26-Dec | 36 | 22 | 29.0 |
| 27-Dec | 37 | 22 | 29.5 |
| 28-Dec | 38 | 21 | 29.5 |
| 29-Dec | 37 | 22 | 29.5 |
| 30-Dec | 38 | 22 | 30.0 |
| 31-Dec | 38 | 22 | 30.0 |

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